

(NASA-CR-171137) PRELIMINARY ENGINEERING
REPORT FOR DESIGN OF A SUBSCALE
EJECTOR/DIFFUSER SYSTEM FOR HIGH EXPANSION
RATIO SPACE ENGINE TESTING Final Report
(Lockheed Missiles and Space Co.) 150 p

LMSC-HREC TR D951414

N84-31273

Unclass
G3/20 20278

PRELIMINARY ENGINEERING REPORT FOR DESIGN OF A SUBSCALE EJECTOR/DIFFUSER SYSTEM FOR HIGH EXPANSION RATIO SPACE ENGINE TESTING

April 1984

FINAL REPORT, CONTRACT NAS8-35051

Prepared for

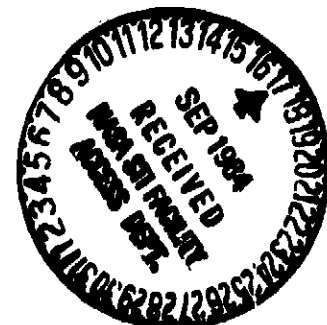
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FOREWORD

This preliminary engineering report is for the design of a subscale jet engine driven ejector/diffuser system for installation at MSFC's Cold Flow Calibration Facility, Building 4554. The work was performed by personnel of the Lockheed-Huntsville Research & Engineering Center under the direction of C.J. Wojciechowski, Project Engineer. The effort was conducted for NASA-Marshall Space Flight Center under Contract NAS8-35051. Included herein are analytical results and preliminary design drawings and plans. This document is the final report required under this contract. The NASA-MSFC Contracting Officer's Representative for this study was Mr. K.E. Riggs, EP23.

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CONTENTS

| <u>Section</u> | | <u>Page</u> |
|-------------------|--|-------------|
| | FOREWORD | ii |
| | LIST OF TABLES | iv |
| | LIST OF FIGURES | iv |
| | NOMENCLATURE | vi |
| 1 | INTRODUCTION | 1 |
| 2 | OBJECTIVES AND REQUIREMENTS | 2 |
| 3 | ENGINEERING ANALYSIS AND DESIGN | 4 |
| | 3.1 Subscale Diffuser Design | 6 |
| | 3.2 Subscale Jet Engine Driven Ejector/Diffuser Safety Analysis | 16 |
| | 3.3 Full Scale Hazard Control Analysis | 22 |
| 4 | SUBSCALE DIFFUSER MECHANICAL/STRUCTURAL DESIGN DRAWINGS | 43 |
| | 4.1 General Description | 43 |
| | 4.2 Government-Furnished Equipment List | 44 |
| | 4.3 Materials Selection | 45 |
| | 4.4 Drawings | 46 |
| | 4.5 Stress Analysis | 46 |
| 5 | PLANS | 47 |
| | 5.1 Instrumentation Plan | 47 |
| | 5.2 Operational Plan | 48 |
| 6 | REFERENCES | 53 |
| <u>Appendixes</u> | | |
| A | Full Scale Gasdynamic Safety Analysis | A-1 |
| B | Subscale Facility Structural Stress Analysis | B-1 |
| C | List of Drawings and Bill of Materials | C-1 |



LIST OF TABLES

| <u>Table</u> | | <u>Page</u> |
|--------------|---|-------------|
| 1 | Worst Case Hazard Assessment | 19 |
| 2 | J-57 Turbojet Engine Characteristics | 22 |
| 3 | Maximum Chapman-Jouguet Detonation Pressures | 25 |
| 4 | Flammability and Detonation Limits (Ref. 6) | 25 |
| 5 | Five Candidate Space Engines for the OTV (Ref. 1) | 33 |
| 6 | Synopsis of Engine Transient Hazard Assessment | 38 |
| 7 | Low Thrust Operation | 41 |
| 8 | 100 Percent Thrust Operation | 42 |

LIST OF FIGURES

| <u>Figure</u> | | <u>Page</u> |
|---------------|--|-------------|
| 1 | 90 Percent Review - Jet Engine Driven Ejector/Diffuser System | 7 |
| 2 | First Stage Ejector Design Summary | 9 |
| 3 | Variation of Minimum Pressure to Which Ejector Will Pump as a Function of Ratio of Mixing-Tube Cross-Sectional Area To Ejector-Throat Area. No Flow Being Pumped (From NASA TN D-23) | 10 |
| 4 | First Stage Ejector Performance as a Function of Ejector Total Pressure | 12 |
| 5 | First Stage Ejector Performance as a Function of Area Ratio | 13 |
| 6 | Water Vapor Condensation (70 F, 50% RH Ambient Air) | 14 |
| 7 | Effects of Ambient Temperature and Relative Humidity on First Stage Ejector Due to Condensation | 15 |
| 8 | Second Stage Ejector Design Summary | 17 |
| 9 | Third Stage Ejector Design Summary | 18 |
| 10 | First Stage Mixing and Worst Case Explosion Hazard Analysis | 20 |
| 11 | Second Stage Mixing and Worst Case Explosion Hazard Analysis | 21 |
| 12 | Hazard Analysis: Worst Case Chapman-Jouguet Detonation Pressure Ratio Characteristics at Prevailing Stream Total Temperatures | 23 |
| 13 | Full Scale AECE-R 10 Percent Thrust Diffuser/Ejector Pressure Distribution | 26 |
| 14 | Full Scale RL10-11B 10 Percent Thrust Diffuser/Ejector Pressure Distribution | 27 |
| 15 | Full Scale RL10-11B 100 Percent Thrust Diffuser/Ejector Pressure Distribution | 28 |

LIST OF FIGURES (Concluded)

| <u>Figure</u> | | <u>Page</u> |
|---------------|--|-------------|
| 16 | H ₂ -COX Static Ignition Limits (Spark Igniter, 4 in. Diameter x 15 in. Long Chamber, PWA FR-303, Nov 61, Ref. 7) | 30 |
| 17 | H ₂ -LOX Engine Exhaust Autoignition Characteristics | 32 |
| 18 | AECE-R Engine Transient Characteristics (Estimated from ASE Engine Data, Refs. 11 and 12) | 35 |
| 19 | RL10A-3-3A Engine Start Transient Characteristics (Ref. 13) | 36 |
| 20 | AECE-R Engine Second Stage Diffuser Transient Characteristics with J-57 Jet Engine Exhaust as Driver (26 lb/sec) | 37 |
| 21 | AECE-R Engine Second Stage Diffuser Transient Operation | 39 |

NOMENCLATURE

| | |
|--------------------|---|
| A | area |
| A* | sonic or throat area |
| GN ₂ | gaseous nitrogen |
| L | length |
| M | Mach number |
| \dot{m}, \dot{w} | flow rate |
| NBP | normal boiling point |
| P, p | pressure |
| R | radius |
| RH | relative humidity |
| r | ejector mass flow to pumped mass flow ratio |
| T | temperature |
| U | velocity |
| \dot{w}_{BL} | J-57 air bleed flow rate |

Greek

| | |
|--------|------|
| τ | time |
|--------|------|

Subscripts

| | |
|---------------------|------------------------------|
| c | cell or chamber |
| D | detonation conditions |
| e _x , ex | ejector mixing tube exit |
| J | pertains to ejector |
| m | mixing tube |
| s | static conditions |
| T | total conditions |
| 1, 2 | downstream of a normal shock |

1. INTRODUCTION

The National Aeronautics and Space Administration long range plans indicate the need for a high expansion ratio, high performance upper stage engine. An altitude simulation test facility will be needed, first to develop the technology for such an engine, and second to provide the development testing for the engine. State-of-the-art steam driven ejector systems are projected to be extremely costly, and as a result NASA has been exploring other less costly means of providing altitude simulation capability. One of the more promising concepts uses the exhaust of conventional jet engines to provide the working fluid for driving the ejectors. In a recent study conducted by Lockheed (Contract NAS8-33981) such a system was found to be analytically feasible. MSFC intends to experimentally demonstrate the concept through the design, fabrication and test of a subscale pilot model.

This document is the final report under this contract. During the course of the design study, several oral presentations were presented to NASA-MSFC at the COR's request. Documentation from these presentations are considered as part of the overall study documentation. Presentations that were given are listed below.

LIST OF ORAL PRESENTATIONS

| Date | Title | Documentation |
|-------------|---|--------------------------|
| 8 Apr 1983 | Program Plan | |
| 23 Jun 1983 | 30 Percent Design Review | LMSC-HREC PR D867208 |
| 24 Aug 1983 | 60 Percent Design Review | LMSC-HREC PR D867272 |
| 23 Feb 1984 | Program Plan for Amended Scope of Work and Review to Date | LMSC-HREC PR D951319 |
| 13 Apr 1984 | Full Scale Gasdynamic Safety Analysis | Appendix A (This Report) |

2. OBJECTIVES AND REQUIREMENTS

This subscale design effort was initiated on 2 April 1983. In the process of developing the subscale design, significant safety questions arose regarding the performance of a full scale system during an actual hot firing of a space engine, especially hydrogen detonation hazards and how they may be controlled. An added scope of work to this contract was issued by MSFC on 11 January 1984 to study the full scale safety issues. The original and added scope of work objectives are listed below:

● Original Objectives

1. Design a subscale working model for future full scale testing of OTV engines in a simulated space environment.
2. Verify that the analyses, design, and performance prediction techniques previously developed are valid and applicable to this concept.
3. Identify for further consideration areas where the analyses and design techniques may not be complete and fully developed and must be supplemented with test data to be obtained in this facility.
4. Provide final design drawings for a prototype system.

● Ammended Scope of Work Objectives.

5. Perform a full scale system safety analysis and determine the mechanisms to suppress detonation by design or operational procedure.
6. Develop full scale configuration detail to support the above objective and determine the design drivers for adjustable ejectors.
7. Provide the design data necessary to make modifications to the subscale system for adequate simulation of the full scale safety issues and performance.

8. Determine the sensitivity of the design to engine physical and performance characteristics.

● Secondary Objectives

These objectives are considerations only, and the prototype design will not be compromised because of them:

1. Use as a test facility for OTV thruster engines with 0.5 to 1.0 lbm/sec flow rate.
2. Provide compatibility with Hot Gas II Facility.

● Requirements

The subscale, pilot model gas driven ejector will be designed to the following requirements:

- A. Test cell pressure: 0.02 psia
- B. Thruster flow rate: 0.50 lbm/sec of gaseous hydrogen
- C. Thruster area ratio: 650:1
- D. Initial inerting with gaseous nitrogen
- E. Capable of being installed at and operating from MSFC's Cold Flow Calibration Facility using a J-57 turbojet engine bleed air and exhaust as the ejector driving medium
- F. Provision for adequate simulation of the full scale facility hazard control mechanism.

Requirement E above was changed after contract award to use the J-57 turbojet engine exhaust instead of the MSFC Hot Gas Facility hot air exhaust to drive the ejector system. Detailed design of the J-57 engine controls, fuel tanks and exhaust ducting was beyond the scope of this contract. Sufficient design of the J-57 exhaust ducting to the ejector system was performed however, to enable a systems compatibility analysis to be performed. The last requirement (F) was added because of the amended Scope of Work.

3. ENGINEERING ANALYSIS AND DESIGN

In the course of performing this task special attention was given to defining such issues and concerns as ejector performance, safety issues such as hydrogen detonation hazards, ejector stability and controllability, ejector cooling requirements, and transient operation. The main analytical computer programs which were used in this study are listed in Refs. 1 through 3. The semi-empirical one-dimensional diffuser/ejector design program developed in the Ref. 1 study, was modified in this study to accommodate temperature dependent ratios of specific heats (γ).

The final subscale ejector/diffuser design as presented herein was driven by the safety analysis results and ejector performance requirements. The mass flows to each ejector stage were dictated by the safety analysis results when the facility is pumping hydrogen (H_2) gas. The main safety criterion arrived at, at the 30 percent design review (Ref. 4), was to design the facility to suppress H_2 detonation hazard potentials. The proposed engineering approach was to:

1. Force the mixture ratio to be out-of-hazard range.
 - First Stage: Operate rich.
 - Second Stage: Operate lean.
 - Third Stage: Dilute second stage effluent to flammability limit.
2. Suppress ignition in first and second stage mixing ducts by operating at low static temperatures and pressures in the presence of condensation fine particulate matter (snow from ambient moisture).
 - First Stage: ($T_g < 200$ K, $T_T < 700$ K, $P_{T,2} < 1.1$ psia)
 - Second Stage: ($T_g < 300$ K; $T_T < 700$ K, $P_{T,2} < 6.6$ psia)

- Third Stage: Barely flammable after mixing, non-detonatable but flammable prior to mixing ($T_g < 660$ K, $T_p < 750$ K, $P_{T,2} < 22.6$ psia)

One of the objectives was to obtain subscale ejector performance data to enable design of a full scale system. Ejector systems are normally point designs, i.e., the blank-off capability and the pumping capability are defined. However, since this was to be a test bed to obtain data for future design, the ejectors had to be designed for variable area ratio to cover the range of anticipated full scale applications. The main reasons for developing and testing variable area ratio ejectors in the subscale design are:

1. Proof-of-concept data can be obtained from a working model.
2. A complete data base can be obtained applicable to full scale design.
3. The full scale ejector/diffuser must accommodate a family of space engines and modes of operation. Each engine will require the ejector system to operate at different ejector driving pressures and flow rates depending on safety considerations and ejector performance.
4. Turbojet engine operation is sensitive to exhaust exit area. Consultation with Pratt & Whitney indicated that this should not be a problem for the jet engine application in this case if the exhaust area can be adjusted to the particular jet engine. Experience has shown that jet engines, although manufactured to the same specifications, have individual characteristics - especially after several years usage - and therefore must be treated separately. Since the jet engines to be used in the prototype, and eventually in the full scale facility, are Air Force surplus engines, they will not be identical in performance. Designing the second and third stage ejector throat areas to be variable will enable fine tuning of the jet engine being used. In addition, the prototype diffuser/ ejector system will not be dependent on a single jet engine. Engine interchangeability is a design feature since the jet engines are surplus Air Force engines.
5. Since the actual ejector throat area (vena contracta) is not known "a priori" due to the compound curvature of the upper

and lower ejector throat surfaces, designing all three ejector throat areas to be variable will facilitate fabrication and assembly of the ejectors to the proper area as compared with the very close tolerance required for a fixed area ratio ejector.

6. The added complication of differential thermal growth between the upper and lower ejector throat surfaces during long duration tests can be adjusted dynamically during the test using real time monitoring of the ejector flow rates. Third stage ejector throat area changes during the tests can be detected by deviation in the low pressure compressor rotor speed falling off the jet engine calibration curve.

3.1 SUBSCALE DIFFUSER DESIGN

The subscale jet engine driven diffuser ejector system at the 90 percent point is shown in Fig. 1. The design of the subscale jet engine driven ejector/diffuser system as presented herein meets all of the requirements presented previously. The features of the subscale design are:

- Three-stage ejector system required to obtain test cell pressure of 0.02 psia
- High pressure compressor bleed air to be utilized to drive the first stage ejector
 - Normal rated power bleed parameters: $P_T \sim 150$ psia; $T_T = 1137$ R; $\dot{W}_{BL} = 8.64$ lbm/sec
 - Military rated power bleed parameters (30 minutes): $P_T = 162$ psia; $T_T = 1182$ R; $\dot{W}_{BL} = 1.65$ lbm/sec
- Turbine exhaust utilized to drive the second and third stage ejectors
 - Normal rated power exhaust parameters: $P_T = 33$ psia; $T_T = 1405$ R; $\dot{W} = 157$ lbm/sec
 - Military rated power exhaust parameters (30 minutes): $P_T = 36$ psia, $T_T = 1500$ R; $\dot{W} = 165$ lbm/sec
- Ejector design to be scale-up of previously tested design.

- FMD = Flow measuring device
 PFCV = Pressure and flow control valve
 CV = Check valve
 EMCV = Electromechanical control valve
 FLOP = Flow Limiting orifice plate

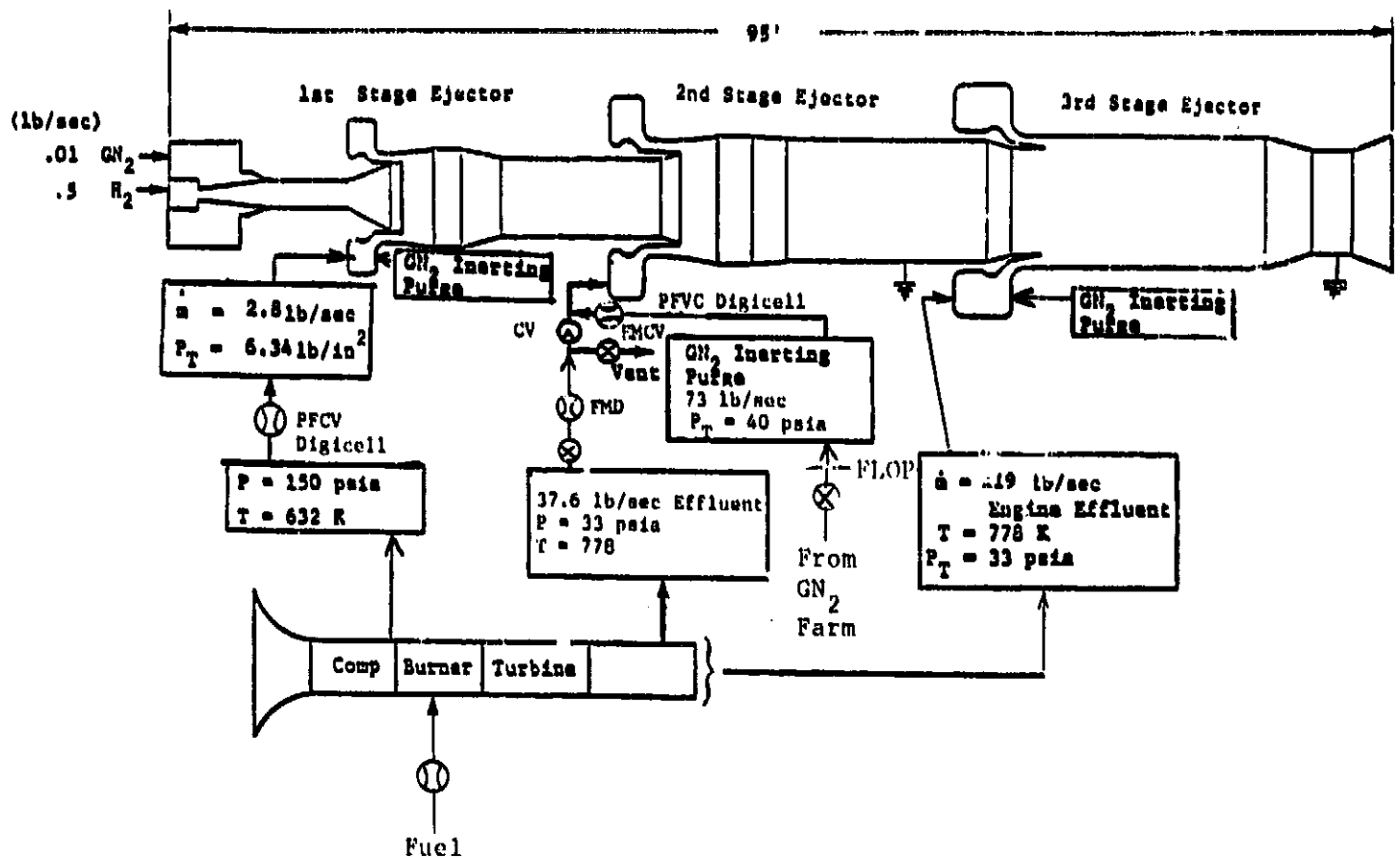
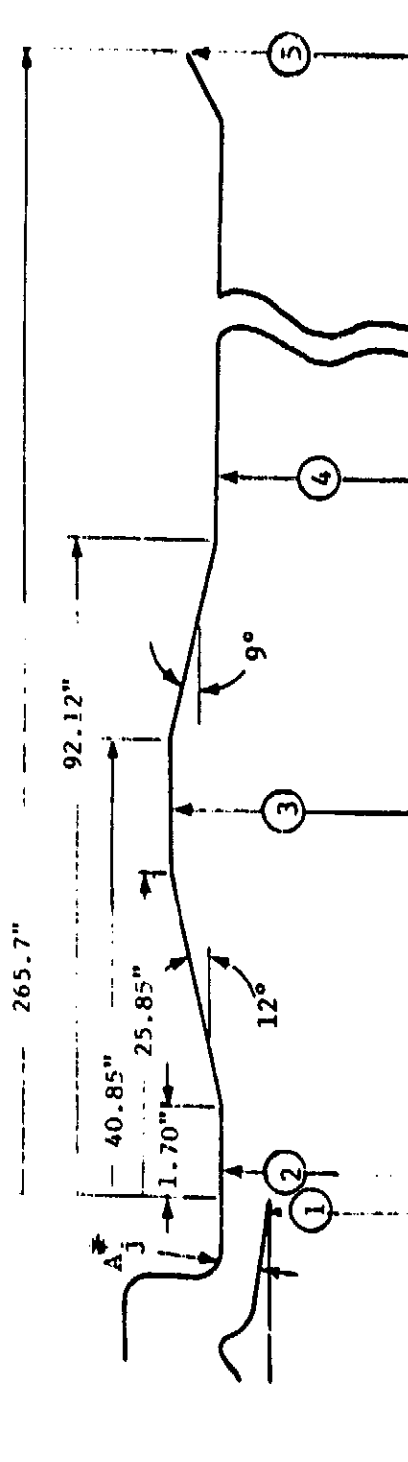


Fig. 1 90 Percent Review - Jet Engine Driven Ejector/Diffuser System

The J-57 turbojet normal rated power level will be used. The design features an altitude test chamber and a 650:1 area ratio H_2 nozzle. To eliminate unnecessary complexities in the subscale model, the H_2 will not be ignited. The H_2 chamber pressure will be 1200 psia. The H_2 nozzle lip pressure will be 0.02 psia. The total pressure of the $H_2 + N_2$ bleed stream entering the first stage ejector will be 3.0 psia, based on the diffuser normal shock recovery pressure.

The design incorporates the rapid turbojet exhaust/ GN_2 switchover design which was developed for the subscale as a result of the full scale safety analysis for a full scale abort condition. The rapid switchover design has been incorporated into the second stage ejector for checkout and verification. The design includes a quick acting (100 msec) Electro-Mechanical Control Valve (EMCV) in the jet exhaust vent line, a Digicell Pressure and Flow Control Valve (PFCV) in the GN_2 line and a full ported swing check valve (CV) in the ejector line downstream of the vent line EMCV. The CV will close rapidly (less than 50 msec) on a negative pressure differential of 0.5 psi. The GN_2 operates at 40 psia and the exhaust operates at 33 psia so that the negative differential will be much greater than 0.5 psi. The same electrical signal would operate both the PFCV and the EMCV. The altitude cell and the first and third stage ejectors are fitted with small GN_2 inerting purge lines to completely purge out all cavities where H_2 could accumulate prior to and after the H_2 tests.

The first stage ejector design summary is presented in Fig. 2. The ejector throat area is designed to be variable and can be completely closed off. The ejector area ratio A_3/A_j^* can be varied from 22 to infinity. The design blank off suction pressure and pumping capacity is shown in Fig. 2 along with the characteristic dimensions. The variation of the minimum cell pressure to exit pressure ratio as a function of ejector area ratio is shown in Fig. 3. Shown in Fig. 3 are Lockheed's analytical results for no second throat and for a second throat compared to experimental data. The first stage ejector is a scale up of the ejector 2 design from Ref. 5. The



Design Conditions with Condensation Effects

$$A_3/A_j^* = 29.52 \quad A_j^* = 25.58 \text{ in}^2$$

$$P_{T_j} = 6.34 \text{ psia} \quad T_{T_j} = 1138 \text{ R}$$

$$\dot{m}_j = 2.79 \text{ lbm/sec}$$

$$r = \dot{m}_j / \dot{m}_1 = 5.47$$

Blank Off Suction Pressure = 0.02 psia

Pumping Capability = 0.51 lbm/sec at 2.8 psia

A_3/A_j^* = Variable from 22 to infinity

$$R_1 = 9.792''$$

$$R_2 = 10.368''$$

$$R_3 = 15.503''$$

$$R_4 = 11.017''$$

$$R_5 = 12.20''$$

Fig. 2 First Stage Ejector Design Summary

ORIGINAL DRAWING
OF POOR QUALITY

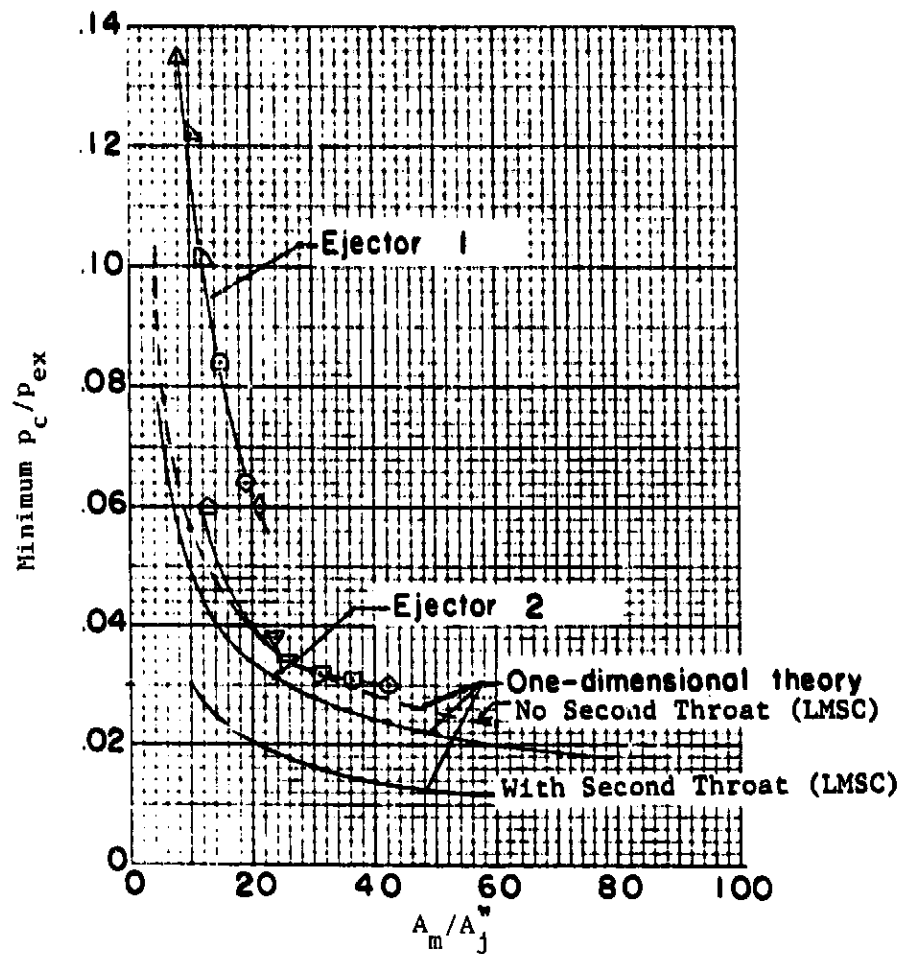


Fig. 3 Variation of Minimum Pressure to Which Ejector will Pump
(As a function of ratio of mixing-tube cross-sectional area
to ejector-throat area. No flow being pumped (from NASA
TN D-23))

ejector 2 design of Ref. 5 was not a second throat ejector design. The first stage ejector performance as a function of ejector total pressure is shown in Fig. 4. The ejector is designed for nominal total pressure of 6.34 psia, at which point the cell pressure will be 0.012 psia without condensation effects. Additional first stage performance data as a function of area ratio is presented in Fig. 5, again without condensation effects. The effects of condensation due to ambient temperature and relative humidity are:

- The primary effect is to add moisture to the ejector driver streams. This moisture condenses in a shock-free condensation front (Wegener and Pouring, Physics of Fluids, Vol. 7, pp. 352-361, 1967), increasing pressure and temperature by release of latent heat to the gas phase in the first and second stages.
- The equilibrium condensed phase is solid (snow), with particle sizes on the order of several hundred Angstroms - a good size for efficient flame suppression.
- Total stream moisture consists of driver engine combustion product and ambient contributions. At low temperatures and humidity, combustion moisture dominates. Under hot, humid ambient conditions air moisture dominates, but does not overwhelm combustion moisture (ratio is approximately 2.5:1 at 100 F, 100% RH corresponding to effluent moisture mole fractions of 0.0876 and 0.0253 (dry air); at design condition (70 F, 50% RH) ratio is approximately 0.5:1, corresponding to an effluent moisture mole fraction of 0.0373.)
- The ejector design can accommodate wide swings in ambient temperature (0 to 100 F) and relative humidity (0 to 100%).

The ejector design ambient conditions are 70 F and 50 percent relative humidity. The calculated onset of water vapor condensation as a function of axial distance from the ejector exit is shown in Fig. 6 for both the first and second stage ejectors. No condensation is predicted for the third ejector stage. The condensation effects on the first stage ejector performance are shown in Fig. 7. The blank off pressure will increase by 28 percent to 0.015 psia which is still comfortably below the 0.02 psia requirement.

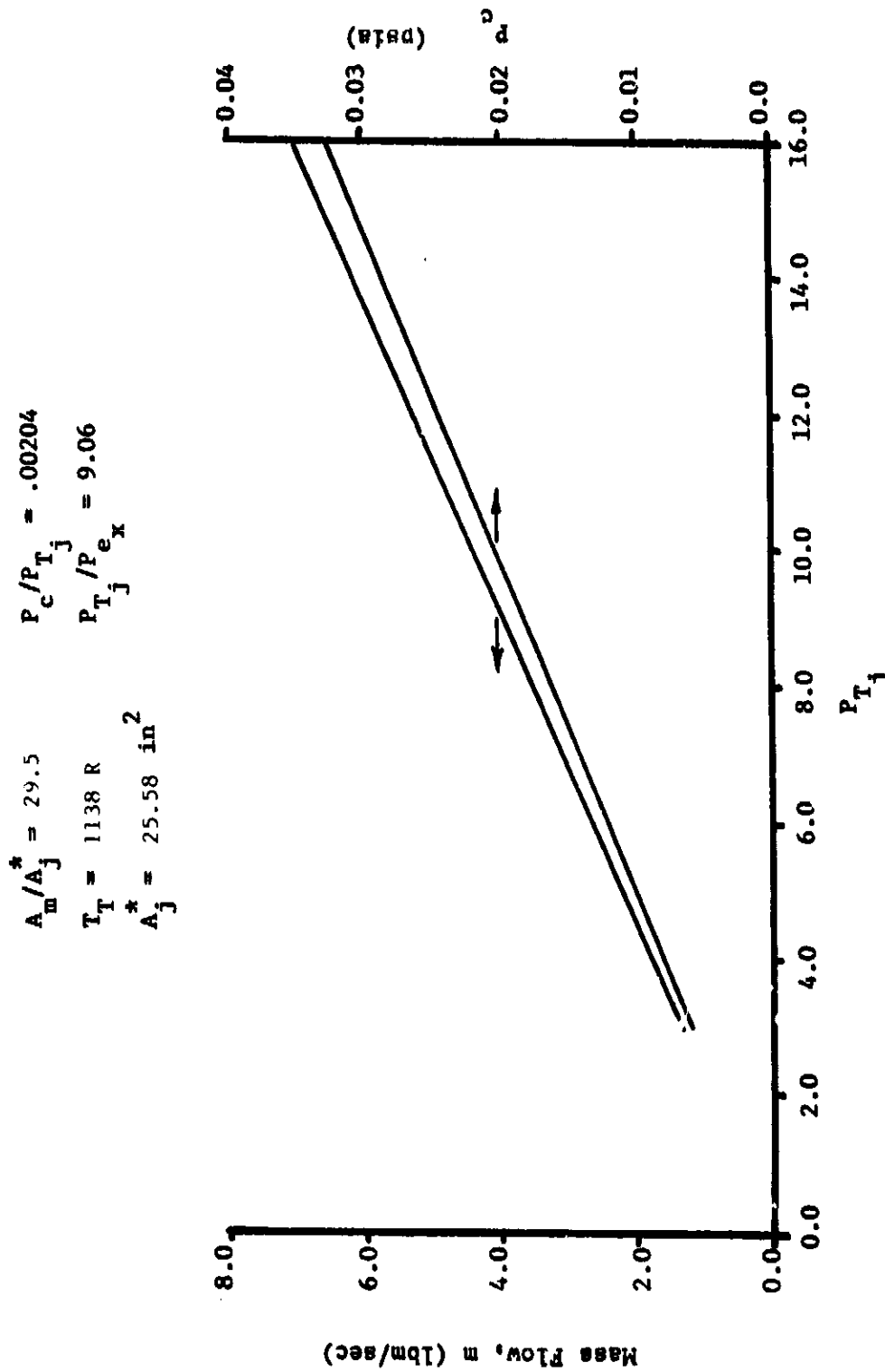


Fig. 4 First Stage Ejector Performance as a Function of Ejector Total Pressure

ORIGINAL INVESTIGATION
OF POOR QUALITY

$$\dot{m} = 2.74 \text{ lbm/sec}$$

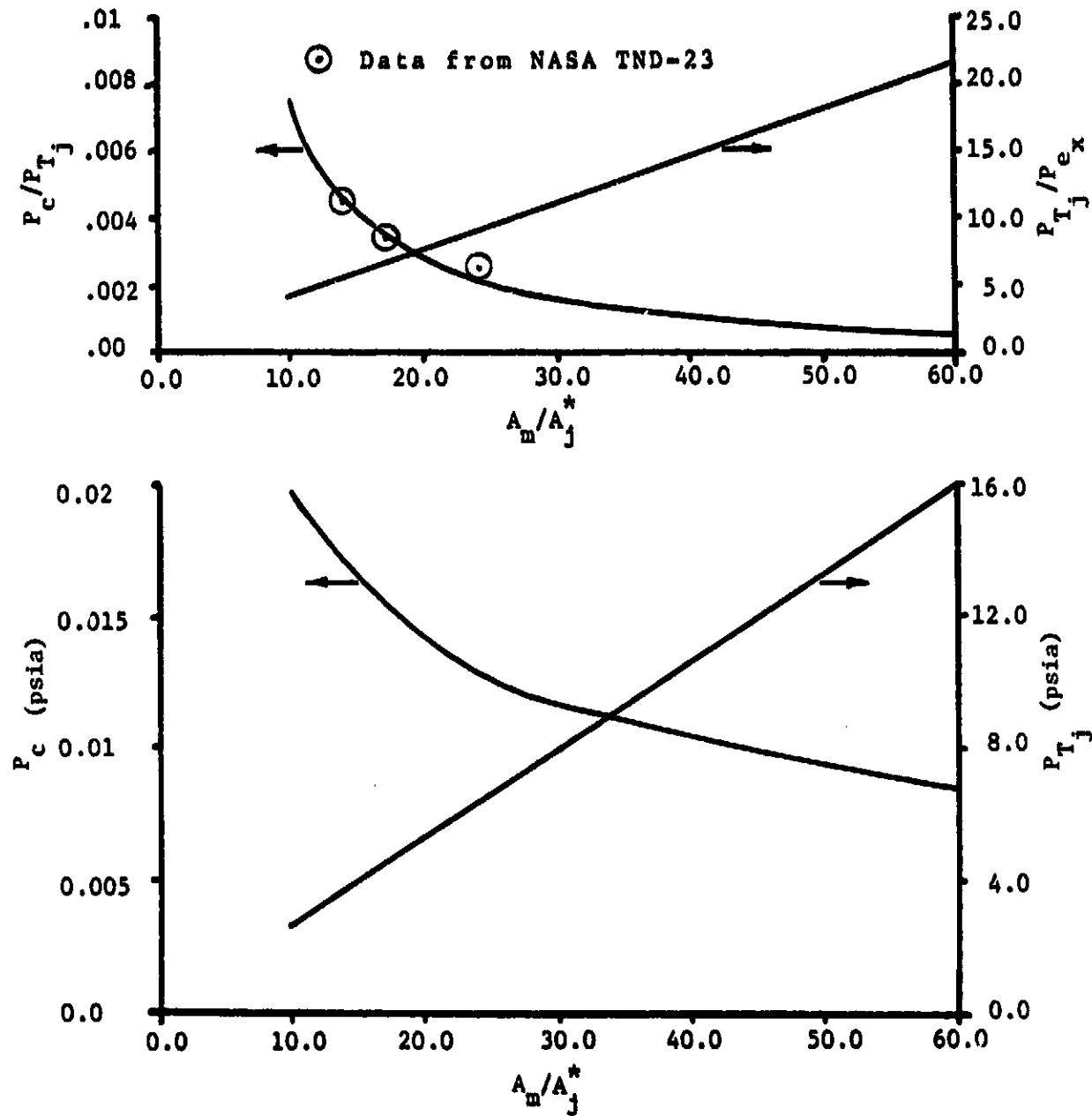


Fig. 5 First Stage Ejector Performance as a Function of Area Ratio

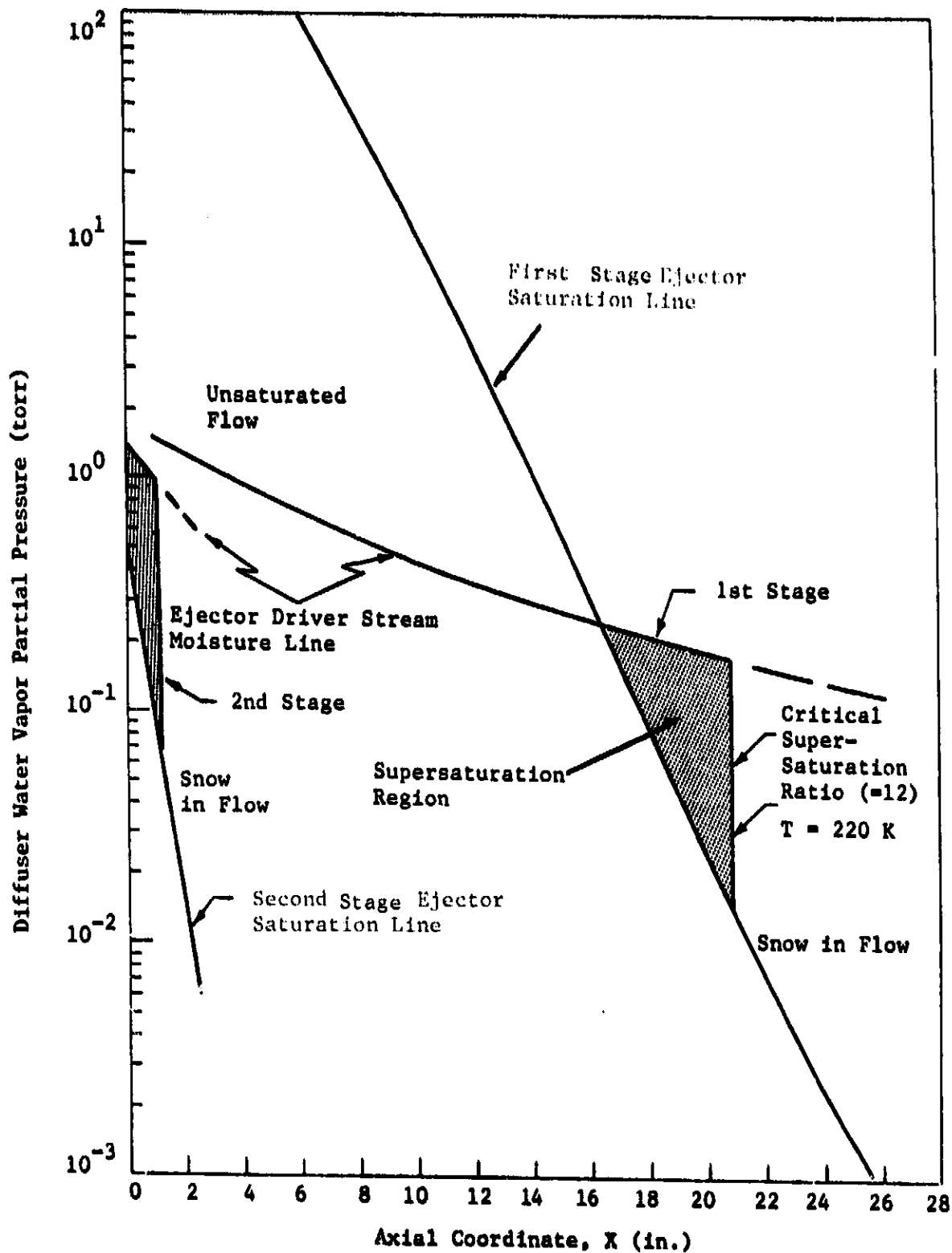


Fig. 6 Water Vapor Condensation (70 F, 50% RH Ambient Air)

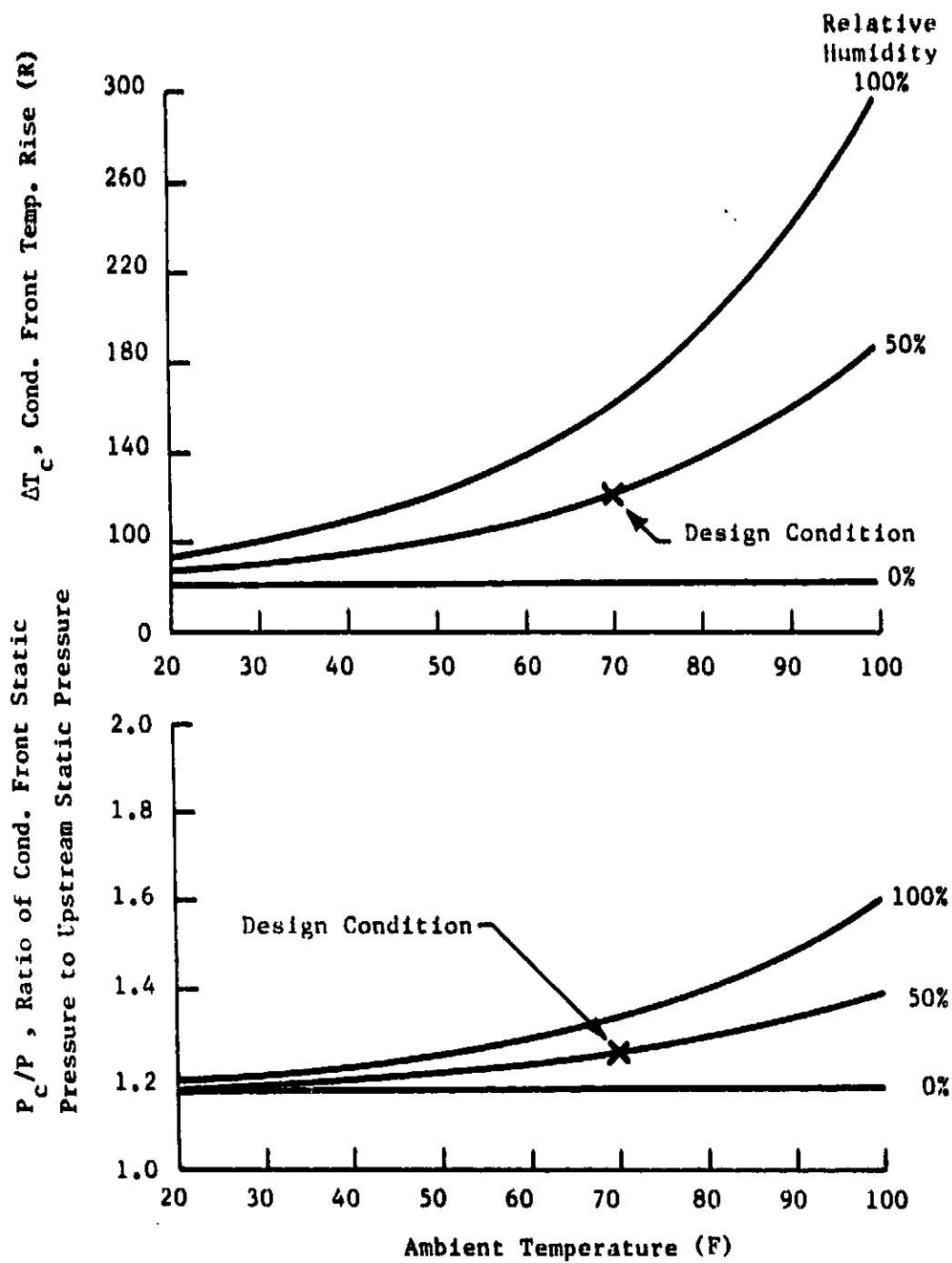


Fig. 7 Effects of Ambient Temperature and Relative Humidity on First Stage Ejector Due to Condensation

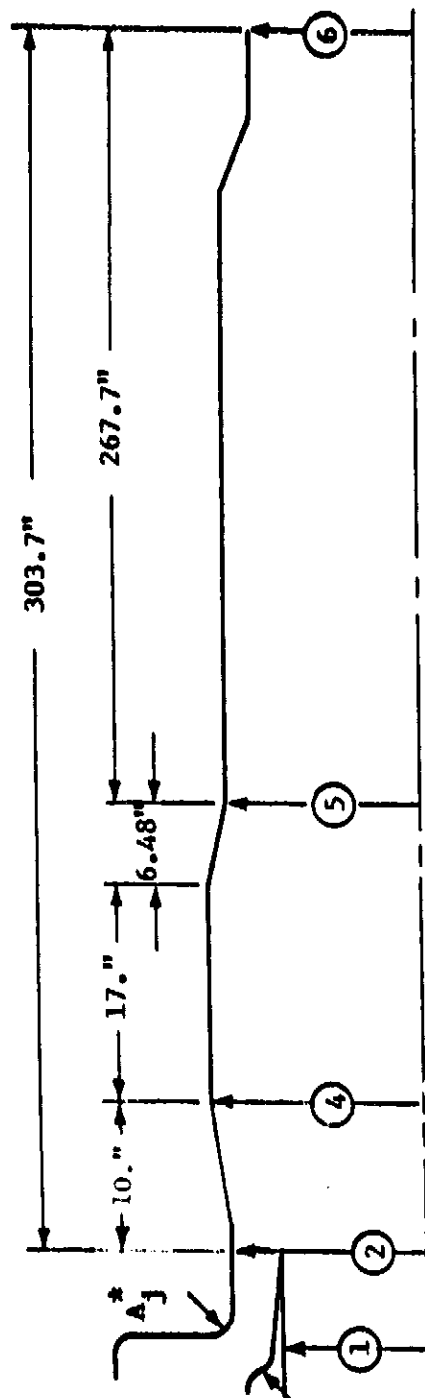
It is of interest to note that the J-57 turbojet engine is already set up with water injection ports at the compressor inlet station. Future full scale space engine hot firing tests could make use of this water injection mechanism to cool the space engine exhaust products. This would relieve some of the diffuser cooling problems and enable the ejectors to operate more efficiently. At the takeoff power setting, the system is capable of 20 gpm water injection rate. The use of water injection at other than the take-off power setting would have to be explored.

The second stage ejector design summary is presented in Fig. 8. The ejector throat area is designed to be variable and can be completely closed off. The ejector area ratio can be varied from 2.38 to infinity. The design blank off suction pressure and pumping capabilities are shown in Fig. 8.

The third stage ejector design summary is presented in Fig. 9. The third stage ejector is designed to operate in all modes of operation. The ejector area ratio can be varied from 2.59 to 10. The third stage ejector is designed to operate by itself using all of the turbojet exhaust products.

3.2 SUBSCALE JET ENGINE DRIVEN EJECTOR/DIFFUSER SAFETY ANALYSIS

The results of this analysis were presented at the 60 percent design review meeting. The key results are presented here. The worst case hazard assessment is presented in Table 1. The main point to be made from Table 1 is that ignition is improbable within the ejector/diffuser tubes. The first stage ejector mixing and explosion hazard analysis results are presented in Fig. 10. The worst case detonation pressures are approximately 8 psia. The second stage ejector mixing and explosion hazard results are presented in Fig. 11. The worst case detonation pressure is 37 psia. It should be pointed out that operating temperatures are too low within the facility to cause a detonation. The facility will be grounded to eliminate a lightning bolt source of energy. However, it is not anticipated that a test would be conducted on threatening weather days.



Design Conditions with Condensation Effects

$$A_{(4)}^*/A_j^* = 11.8 \quad A_j^* = 80.86 \text{ in}^2$$

$$P_{T_j} = 33 \text{ psia} \quad T_{T_j} = 1400 \text{ R}$$

$$\dot{m}_j = 37.3 \text{ lbm/sec}$$

$$r = \dot{m}_j / \dot{m}_{(1)} = 11.3$$

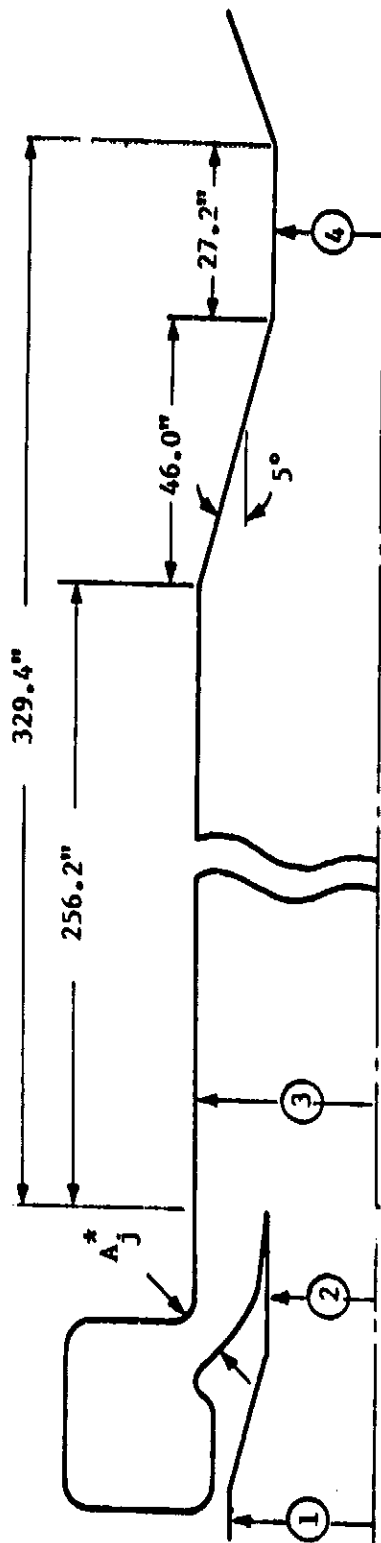
$$\text{Blank Off Suction Pressure} = 0.20 \text{ psia}$$

$$\text{Pumping Capability} = 3.3 \text{ lbm/sec at } 0.82 \text{ psia and } 802 \text{ R}$$

$$A_{(4)}^*/A_j^* \text{ Variable from } 2.38 \text{ to Infinity}$$

$$\begin{aligned} R_{(1)} &= 12.20'' \\ R_{(2)} &= 16.0'' \\ R_{(4)} &= 17.42'' \\ R_{(5)} &= 16.73'' \\ R_{(6)} &= 14.33'' \end{aligned}$$

Fig. 8 Second Stage Ejector Design Summary



Design Conditions

$$A_3/A_j^* = 4.09 \quad A_j^* = 257.31 \text{ in}^2$$

$$P_{Tj} = 33 \text{ psia} \quad T_{Tj} = 1400 \text{ R}$$

$$\dot{m}_j = 118.77 \text{ lbm/sec}$$

$$A_3/A_j^* \text{ Variable from 2.59 to 10}$$

$$r = \dot{m}_j / \dot{m}_2 = 2.93$$

Blank Off Suction Pressure - 0.98 psia

Pumping Capability

40.6 lbm/sec at 5.5 psia and 1235 R

30.5 lbm/sec at 5.5 psia and 2200 R

$$R(1) = 16.73''$$

$$R(2) = 14.33''$$

$$R(3) = 18.30''$$

$$R(4) = 14.28''$$

Fig. 9 Third Stage Ejector Design Summary

Table 1 WORST CASE HAZARD ASSESSMENT

Kinetics Ignition Delay Behind Normal Shock in Duct

$$\tau_{\text{ignition}} = \frac{8 \times 10^{-9} \exp 9600/T, K}{P, \text{ atm}} \text{ sec (NASA TP 1457, Aug 79, Huber et al.)}$$

First Stage: ($T_{S,2} = 429 \text{ K}$; $M_2 = 0.454$; $U_2 = 1073 \text{ ft/sec}$;
 $P_{S,2} = 0.821 \text{ psia}$)

$\tau_{\text{ignition,NS}} = 760 \text{ sec}$ No problem, by a wide
 $L_{\text{ignition,NS}} = 8.2 \times 10^5 \text{ ft}$ margin of safety.

Second Stage: ($T_{S,2} = 663 \text{ K}$; $M_2 = 0.444$, $U_2 = 801 \text{ ft/sec}$;
 $P_{S,2} = 5.52 \text{ psia}$)

$\tau_{\text{ignition,NS}} = 4.2 \times 10^{-2} \text{ sec}$ Safe, with no igni-
 $L_{\text{ignition,NS}} = 33.5 \text{ ft}$ tion in duct.

Third Stage: ($T_{S,2} = 701 \text{ K}$; $M_2 = 0.644$; $U_2 = 1128 \text{ ft/sec}$;
 $P_{S,2} = 16.7 \text{ psia}$)

$\tau_{\text{ignition,NS}} = 6.2 \times 10^{-3} \text{ sec}$ Safe, with potential
 $L_{\text{ignition,NS}} = 7.0 \text{ ft}$ gentle ignition in
open duct downstream
of shock.

- The Available Ignition Source (i.e., the Jet Engine Exhaust) Operates at Temperatures Too Low to Ignite the H_2 Fuel Within the Flow Facility.

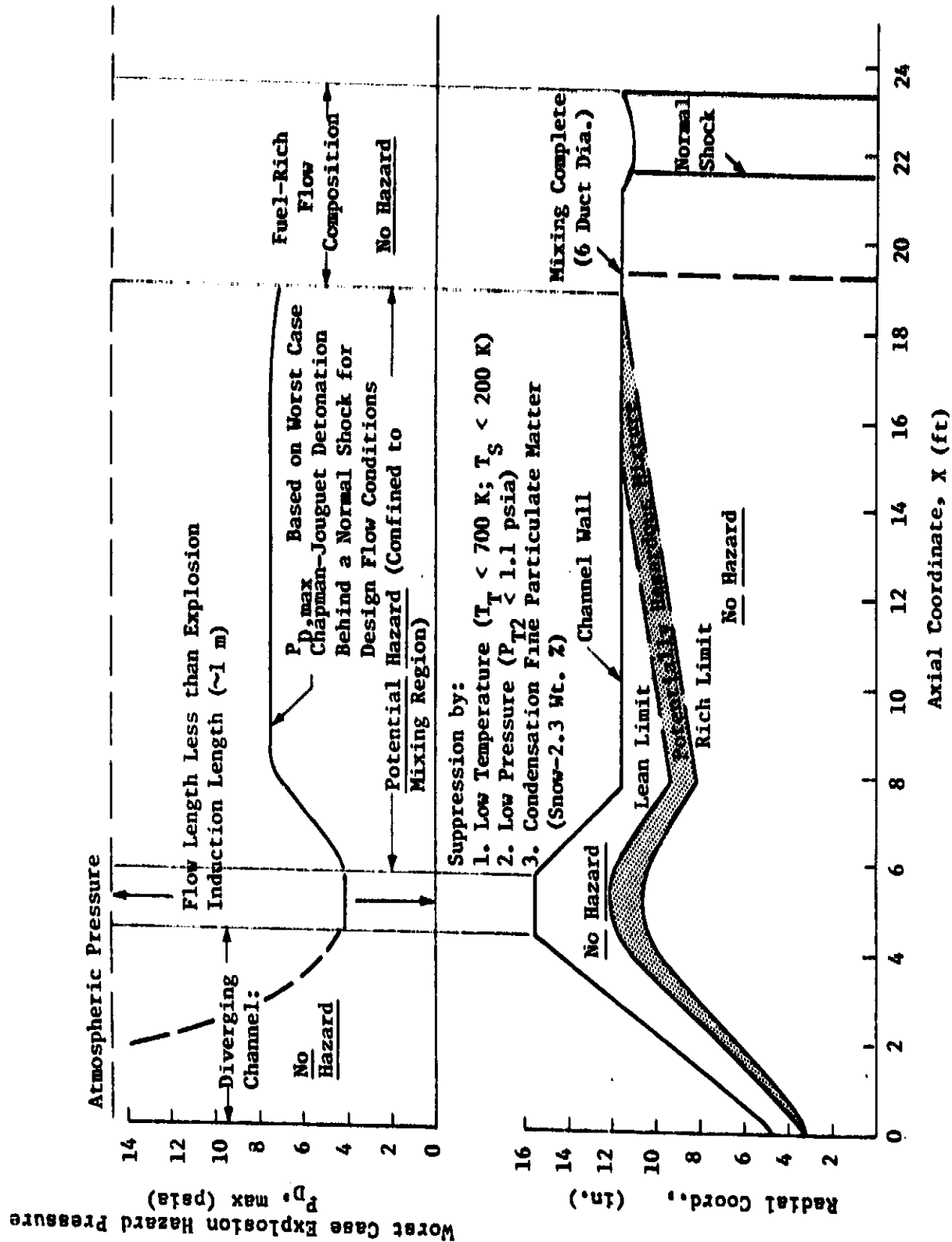


Fig. 10 First Stage Mixing and Worst Case Explosion Hazard Analysis

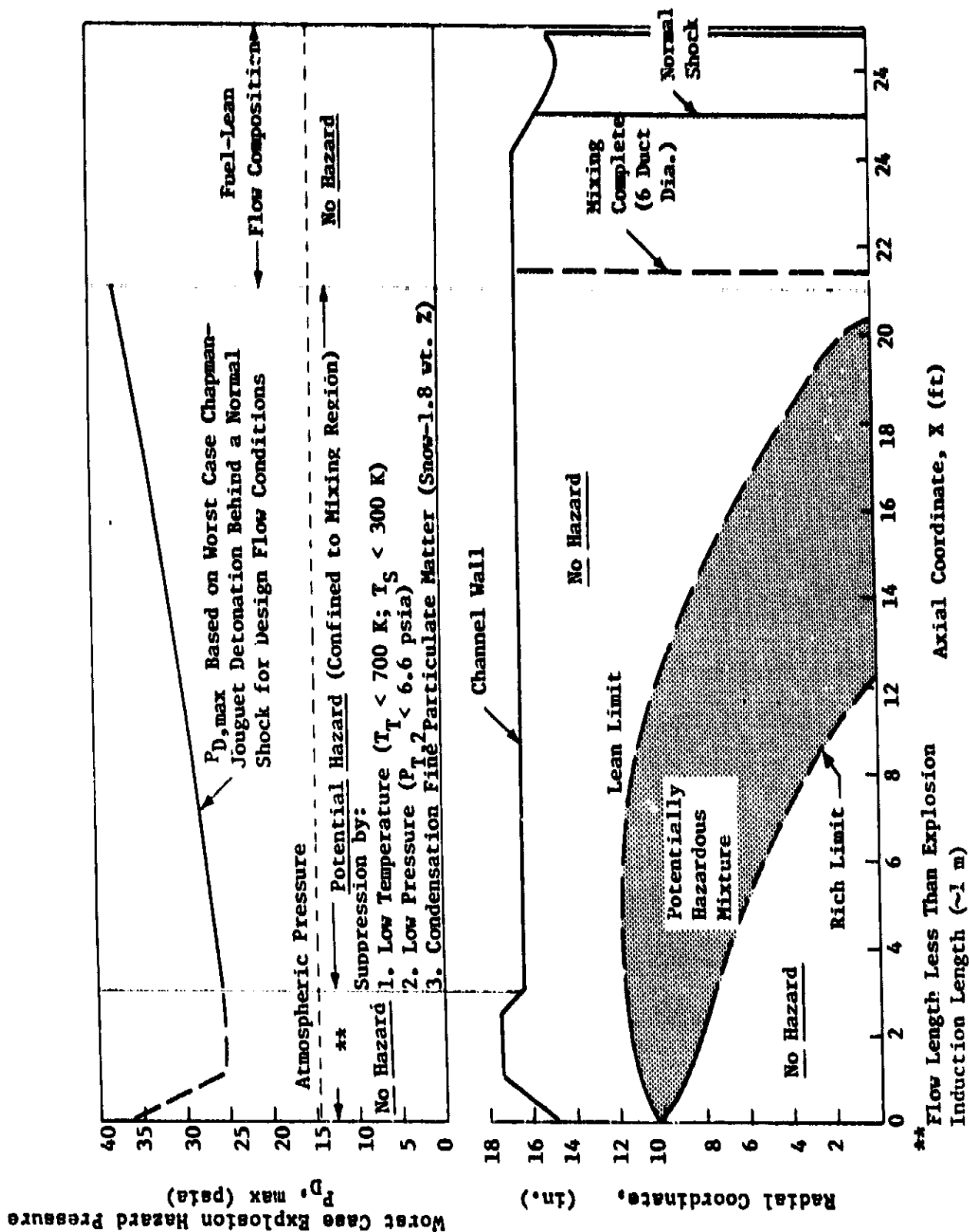


Fig. 11 Second Stage Mixing and Worst Case Explosion Hazard Analysis

3.3 FULL SCALE HAZARD CONTROL ANALYSIS

The hazard to be controlled is a potential detonation of unburned space engine hydrogen fuel within the diffuser/ejector duct work. In the past, this hazard has been eliminated by using an inert driver - steam. With the proposed use of jet engine effluent as the driving medium a potential for explosion of mixtures exists, as the jet engines are operated fuel-lean and consequently have an appreciable oxygen content (see Table 2).

Table 2 J-57 TURBOJET ENGINE CHARACTERISTICS

| | |
|------------------------------|---|
| Cruise-Rated Air Flow Rate: | 157 lb-sec ⁻¹ (70 F, 50% RH) |
| Cruise-Rated Fuel Flow Rate: | 7,050 lb-hr ⁻¹ |
| Engine Exhaust - | |
| Total Flow Rate: | 158.96 lbm-sec ⁻¹ |
| Total Temperature: | 1400 R |
| Total Pressure: | 33 psia |
| Composition - | |
| N ₂ | 77.03 vol.% |
| O ₂ | 16.70 vol.% |
| CO ₂ | 2.51 vol.% |
| H ₂ O | 3.74 vol.% |
| NO _x | 87 ppm |
| CO | 60 ppm |
| CH ₄ | 84 ppm |

3.3.1 Worst Case Hazard Analysis

To place the potential hazard in perspective consider Fig. 12 in which computed Chapman-Jouguet detonation pressure ratios are plotted as a function of mixture H₂ concentration for mixtures of space engine effluent

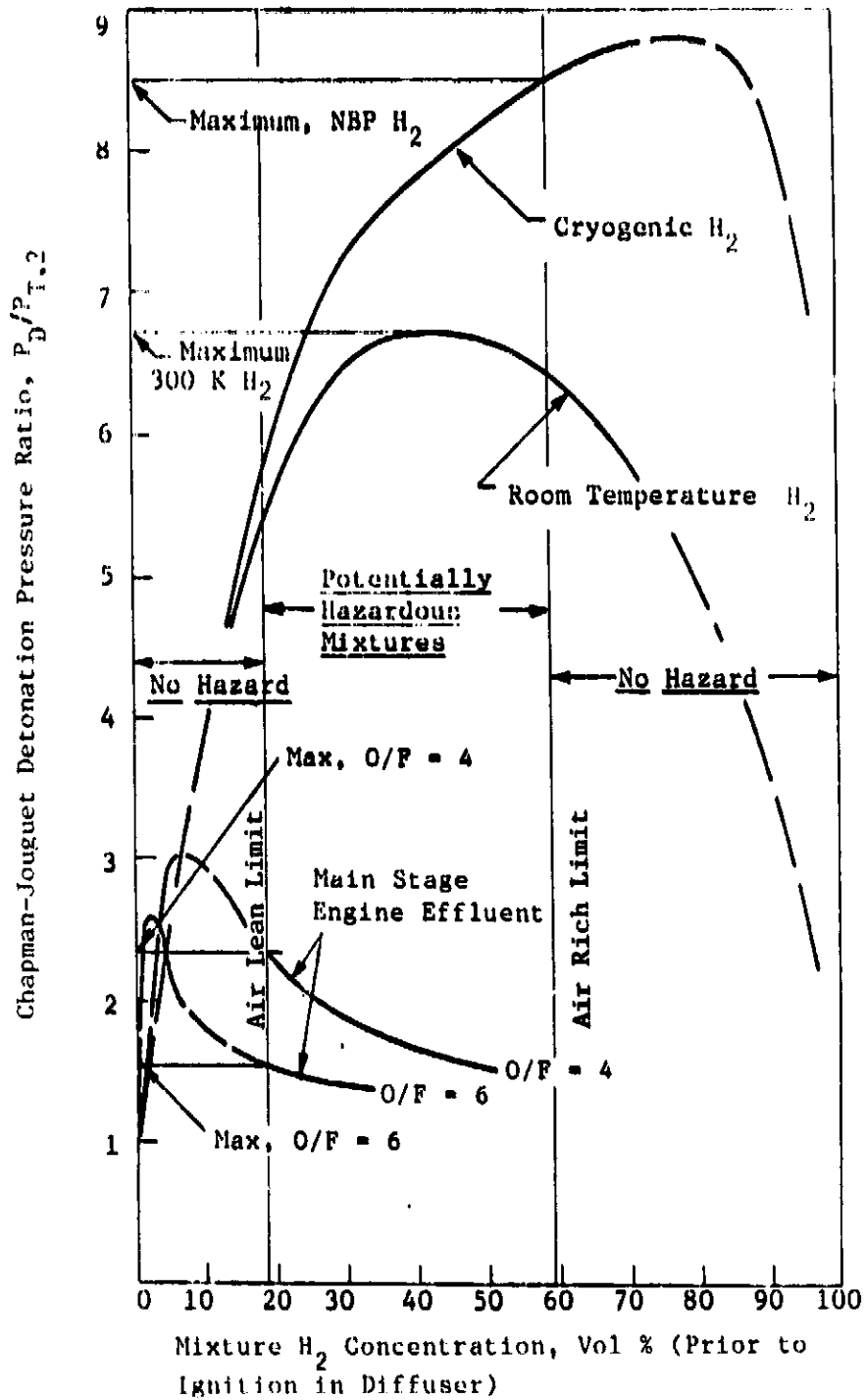


Fig. 12 Hazard Analysis: Worst Case Chapman-Jouquet Detonation Pressure Ratio Characteristics at Prevailing Stream Total Temperatures

and J-57 turbojet driver effluent at 0.5 atm initial pressure*. As is evident from the figure the worst case overpressures occur when 100 percent H_2 is exhausted from the test engine and are higher for cryogenic H_2 than for regeneratively heated H_2 at room temperature. For main stage space engine operation at engine O/F ratios of 4 or 6 a considerable decrease in the worst case detonation pressure ratio results. This is a direct consequence of the higher initial mixture temperature due to combustion in the space engine. Table 3 summarizes the maximum, i.e., worst case, potential detonation pressure ratios for the various space engine effluents considered, using J-57 turbojet exhaust as the diffuser/ejector driver. The corresponding worst case detonation pressures possible in each stage at 10 percent and 100 percent thrust engine operation are also shown in Table 3. These data are based on the calculated pressure distributions for the full scale facility shown in Figs. 13, 14, and 15.

3.3.2 Hazard Control Analysis

• Transient Operations

As is evident from Fig. 12 and Table 3, the maximum potential hazard exists during cold flow operations, which normally are tests of short duration. The highest potential overpressure would occur in the third ejector stage and could approach an upper limit of 272 psia, with cryogenic H_2 . (Room temperature H_2 represents somewhat less of a potential hazard, but would however be more readily ignited.) A nearly 100 percent H_2 engine flow can also be encountered during engine startup and shutoff transients, as discussed in more detail in Section 3.3.3.

* These computations were performed using the NASA-Lewis CEC code (Ref. 2). The detonation pressure ratios were found to be largely insensitive to initial pressure over the range of interest (i.e., subatmospheric) to this study.

Table 3 MAXIMUM CHAPMAN-JOUQUET DETONATION PRESSURES
 (P_D) = Detonation Pressure; $P_{T,2}$ = Initial Total Pressure
 Driver: J-57 Jet Engine Exhaust

| Space Engine Condition | $(P_D/P_{T,2})_{\max}$ | Worst Case Detonation Pressure (psia) | | | |
|-------------------------------------|------------------------|---------------------------------------|------------------|------------|------------|
| | | Thrust (%) | 1st Stage | 2nd Stage | 3rd Stage |
| Cold Flow of Cryogenic H_2 | 8.5 | 10 100 | 39 (Shut Off) | 165 124 | 272 253 |
| Cold Flow of Room Temperature H_2 | 6.7 | 10 100 | 31 (Shut Off) | 130 98 | 214 200 |
| Main Stage, Engine O/F = 4 | 2.3 | 10 100 | 11 (Shut Off) | 45 34 | 74 69 |
| Main Stage, Engine O/F = 6 | 1.5 | 10 100 | 7 (Shut Off) | 29 22 | 48 45 |

To control the startup/shutoff transient hazard, and also to allow short duration cold flow engine acceleration tests without oxidizer, Lockheed proposes the use of tank farm nitrogen as driver for the first and second diffuser/ejector stages during start/stop transients, and also during short duration cold flow tests without oxidizer flow. Sufficient GN_2 is to be used to dilute the peak H_2 flow in the overall mixture leaving the 2nd stage to below the lean detonation limit (see Table 4), i.e., to about 19 vol.% or less.

Table 4 FLAMMABILITY AND DETONATION LIMITS (Ref. 6)

| | Hydrogen-Air | H_2 -J57 Jet Engine Effluent* |
|-----------------------------|-----------------|---------------------------------|
| Flammability Limits (vol.%) | $4.0 < F < 75$ | $4.2 < F < 66$ |
| Detonation Limits (vol.%) | $18.3 < D < 60$ | $19 < D < 55$ |

* Estimated, based on effects of dilution of air with N_2 , CO_2 , and H_2O as reported in Ref. 6.

ORIGINAL
OF POOR QUALITY

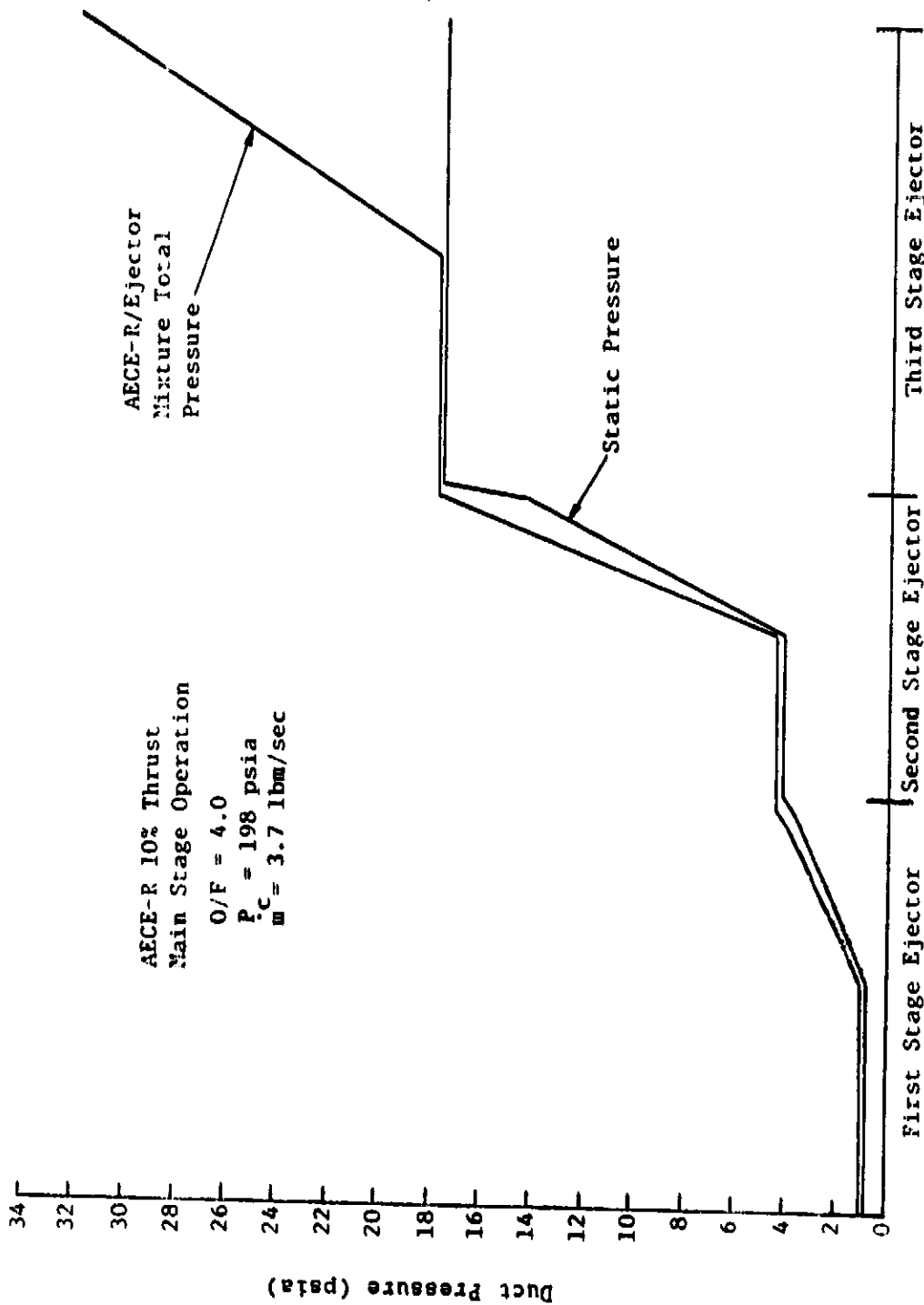


Fig. 13 Full Scale AECE-R 10 Percent Thrust Diffuser/Ejector Pressure Distribution

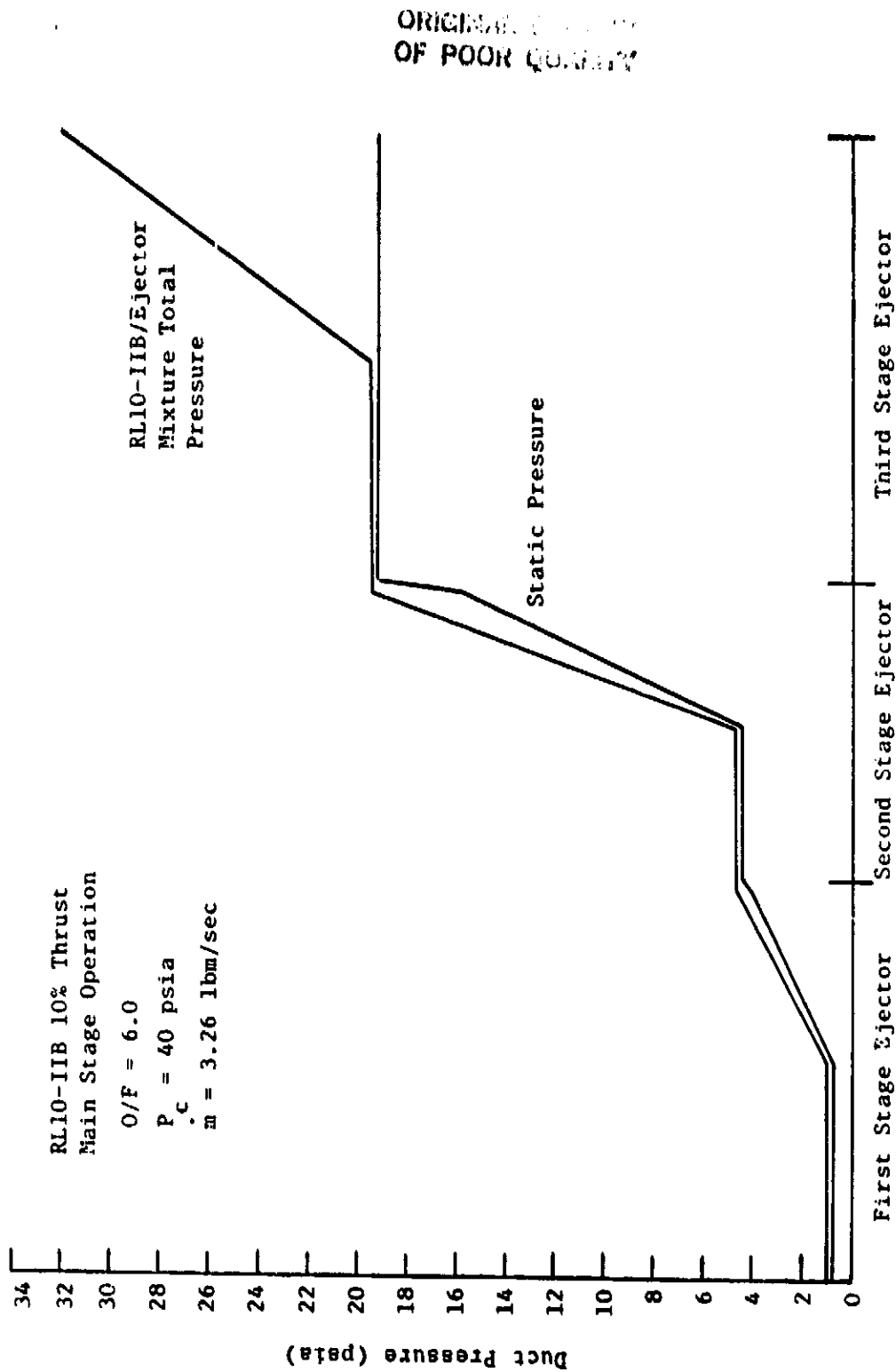


Fig. 14 Full Scale RL10-IIB 10 Percent Thrust Diffuser/Ejector Pressure Distribution

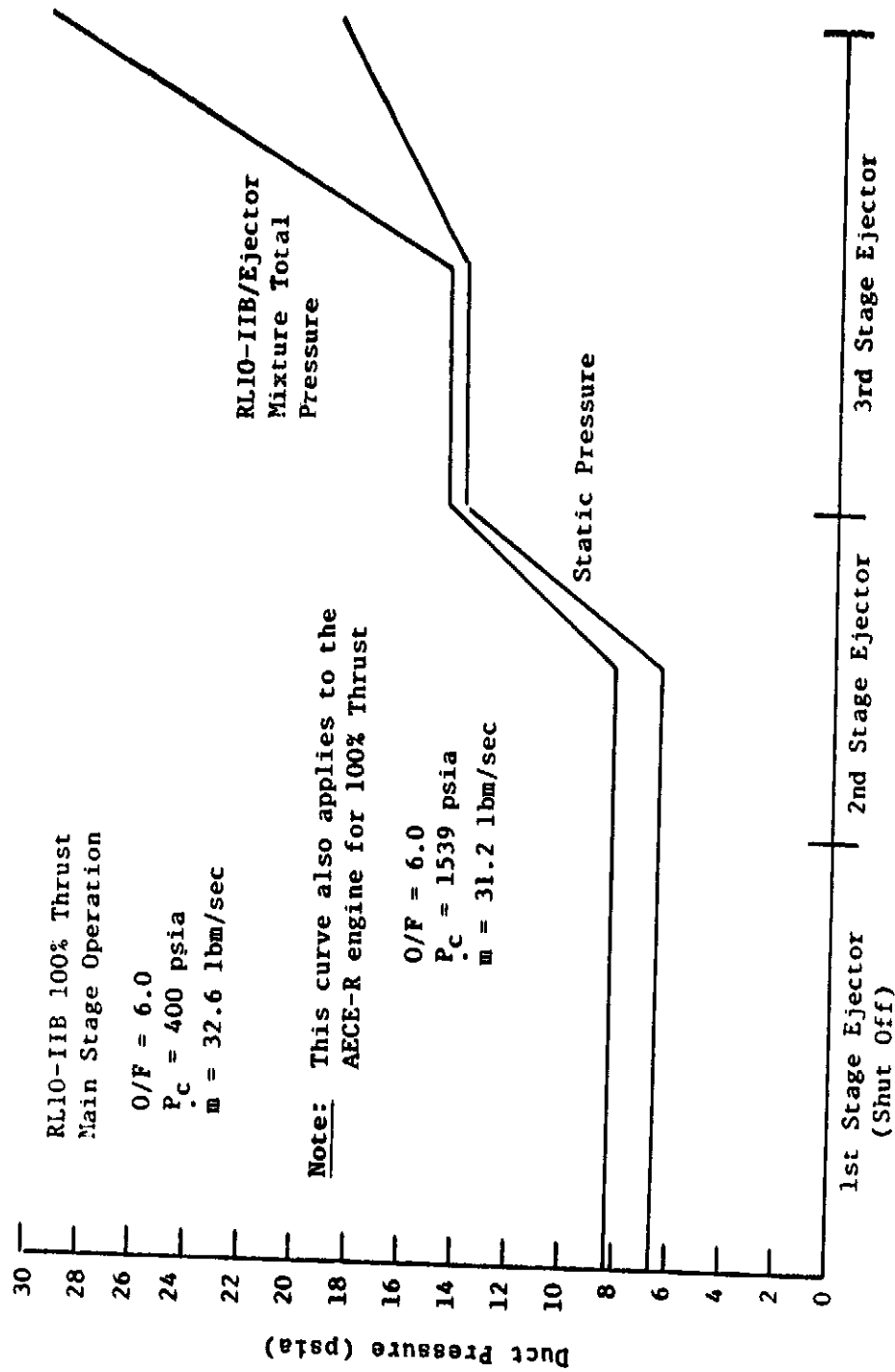


Fig. 15 Full Scale RL10-IIB 100 Percent Thrust Diffuser/Ejector Pressure Distribution

• Main Stage Operation

Long duration tests - 30 minutes or more - are required for the engines in main stage operation, at both low and high thrust levels. Tests of such length preclude use of GN_2 as driver, even in the first and second stages of the diffuser/ejector. Therefore at main stage the J-57 jet engines' exhausts will be used as driver in all of the stages, and the hazard control will be to ensure that the space engine excess fuel is combusted continuously in each of the stages as rapidly as it mixes with the driving medium. Three conditions that must be met simultaneously to achieve this are:

1. Mixture compositions must lie within the flammability limits summarized in Table 4. This is a restriction which is only operative on the fuel-rich side of engine operation in the present analysis. If mixtures are already too lean to burn, they are also too lean to detonate and are no longer a potential hazard. On the rich side of the flammability limits, mixtures exhausting from the space engines with greater than 66 to 75 percent H_2 (Table 4) - corresponding to engine O/F ratios of 2.5 to 2.0 or less - might require further dilution by the driving medium prior to the recommencing of combustion. If other conditions are correct it would seem probable that burning would resume in such mixtures prior to their being diluted sufficiently to enter into the detonable range - 55 to 60 percent H_2 . To be prudent, however, engine mixtures entering the diffuser with an O/F ratio less than 2.0 should be regarded as potentially hazardous (see also below).
2. Static pressure must everywhere be higher than the lower ignition limit pressure to assure the continuity of the combustion process. Spark igniter ignition limits for H_2 -GOX mixtures at room temperature obtained by Pratt & Whitney (Ref. 7) in a relatively small chamber (4 in. diameter, 15 in. long) are shown in Fig. 16, which indicates a lower limit pressure of 0.2 psia for these conditions. Also shown is the lowest static pressure (from Figs. 13, 14, and 15) in the proposed full scale diffuser facility, i.e., 0.7 psia. The latter pressure is the lowest encountered, in the first stage, at low space engine thrust levels. It is, however, sufficiently high that combustion of hot main stage exhaust proceeds as the gases mix even at the lowest pressure encountered.

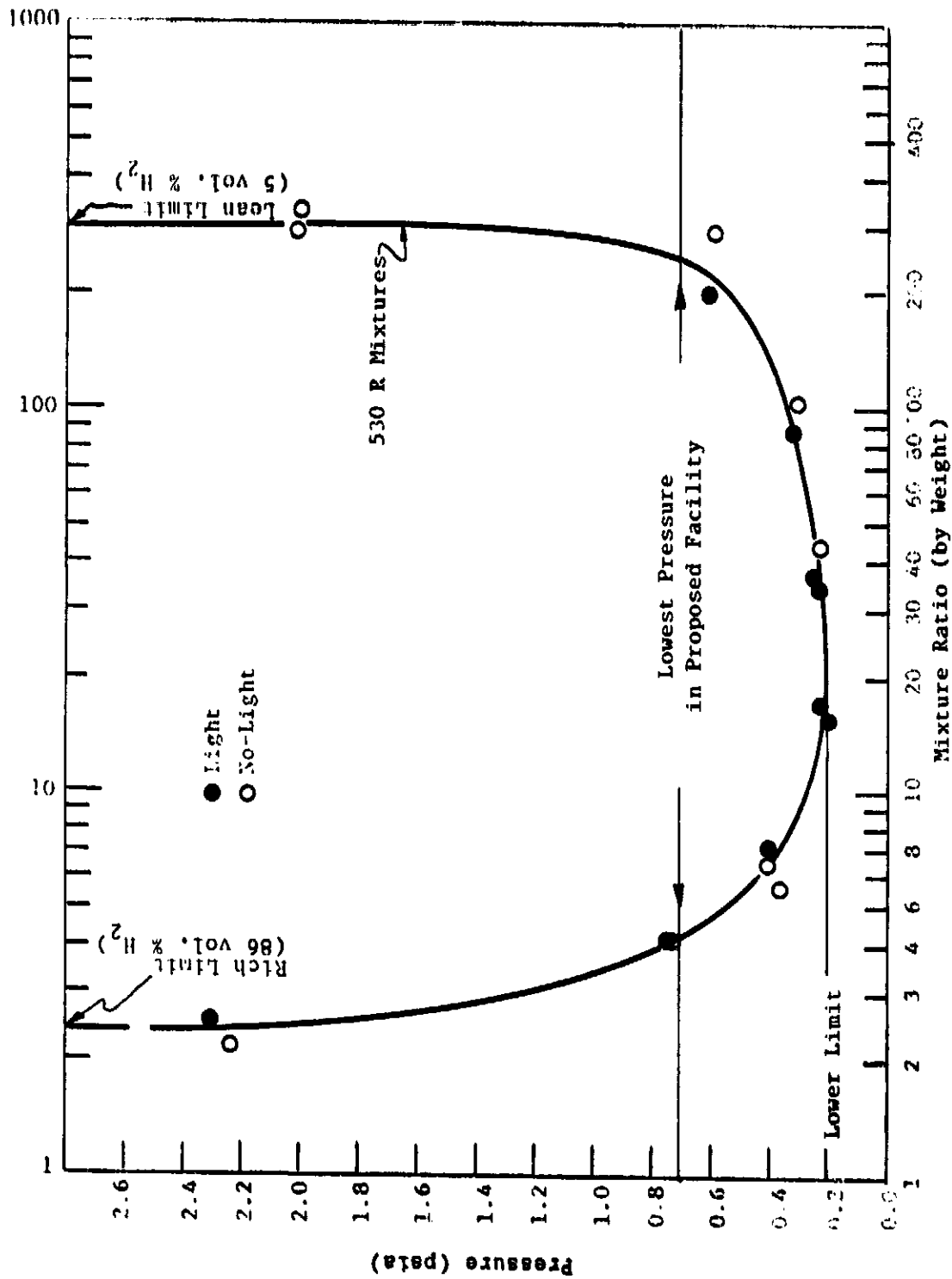


Fig. 16 H₂-GOX Static Ignition Limits (Spark Igniter 4 in. Diameter x 15 in. Long Chamber, PWA FR-303, Nov 61, Ref. 7)

It is useful in this regard to note that the lower pressure limit obeys an inverse response to increases in temperature (exponential response), vessel size and ignition source strength (see, e.g., Refs. 8 and 9). At main stage engine operation all of these factors are operative in a direction to assure continuous combustion.

3. Static temperature must be sufficiently high everywhere that kinetics are rapid with respect to mixing. In Fig. 17, hydrogen-air autoignition delay times from Ref. 10 are shown as a function of static temperature. These delay times - inversely proportional to pressure - are a measure of the rapidity of hydrogen combustion.

As indicated, at static temperatures above 1300 K the product of pressure and ignition delay is approximately 10^{-5} atm-sec or less. Thus even at the 0.7 psia lowest static pressure (first stage, 10 percent thrust) delay times will be shorter than 2×10^{-4} sec for $T > 1300$ K - corresponding to engine O/F ratios greater than 2.0 accelerated to Mach numbers which are restricted by design to 2.0 or less within the diffuser/ejector facility. Noting that gas residence times in the first, second, and third stages are approximately 5, 10, and 30 msec, respectively, this ensures that the gases burn as rapidly as they mix, under all conditions, for engine O/F ratios of 2.0 or greater.

3.3.3 AECE-R and RL10-IIB Space Engine Transient Characteristics

Operating parameters of five candidate space engines for the orbital transfer vehicle are shown in Table 5 from Ref. 1. Of these advanced engines, two - the AECE-R and the RL10-IIB - were selected for analysis of potential transient operational test hazards in the proposed diffuser facility.

AECE-R engine startup transient and main stage characteristics were derived from ASE data presented in Ref. 11; shutoff data came from Ref. 12. Similar data for the RL10-IIB engine were derived from RL10A-3-3A data

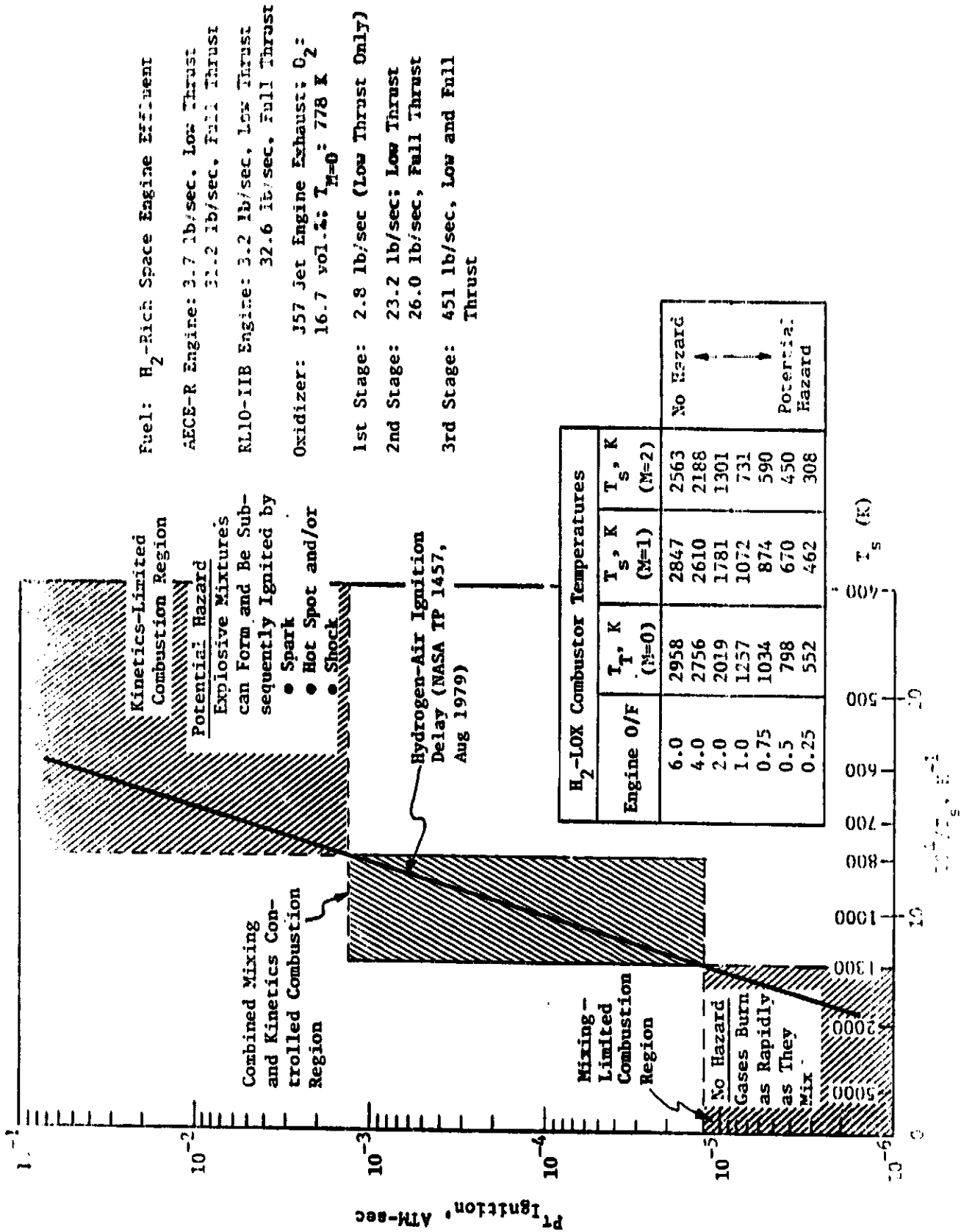


Fig. 17 H_2 -LOX Engine Exhaust Autoignition Characteristics

Table 5 FIVE CANDIDATE SPACE ENGINES FOR THE OTV (REF. 1)

| Parameter | Units | AECE-A | AECE-P | AECE-R | ASE | RL10-11B |
|---------------------------------------|--------|---------------------|---------------------|---------------------|---------------------|---------------------|
| Thrust, Full | 1b | 15000 | 15000 | 15000 | 20000 | 15000 |
| Thrust, Low | 1b | 2000 | 1500 | 1800 | 1850 | 1500 |
| Maximum Test Duration @ MR = 6.0 | | | | | | |
| Full Thrust | sec | 1200 | 1200 | 1200 | 1200 | 1200 |
| Low Thrust | sec | 2500 | 2500 | 2500 | 2500 | 2500 |
| Gimbal Capability | - | None | None | None | None | None |
| Propellants | | LOX/LH ₂ | LOX/LH ₂ | LOX/LH ₂ | LOX/LH ₂ | LOX/LH ₂ |
| Mixture Ratio, Full Thrust | - | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| Low Thrust | - | 6.0 | 6.0 | 4.0 | 2.0 | 6.0 |
| Nozzle Area Ratio | - | 473 | 642 | 625 | 400 | 205 |
| Engine Envelope: | | | | | | |
| Outside Diameter @ Noz. Exit | in. | 62.7 | 66.1 | 63.25 | 58.08 | 73.0 |
| Inside Diameter @ Noz. Exit | in. | 60.7 | 64.1 | 61.25 | 56.08 | 71.0 |
| Length, Gimbal Pad to Noz. Exit | in. | 120 | 114 | 117 | 100 | 110 |
| Length, Gimbal Pad to Inlet Flange | | | | | | |
| LOX | in. | 12 | 12 | 12 | 27.1 | 10 |
| LH ₂ | in. | 15 | 15 | 15 | 36.87 | 10 |
| Engine Weight | 1b | | | | | |
| Chamber Pressure, Full Thrust | psia | 1200 | 1505 | 1539 | 2028 | 400 |
| Chamber Pressure, Low Thrust | psia | 160 | 150 | 198 | 187 | 40 |
| Noz. Exit Wall Press., Full Thrust | psia | 0.196 | 0.163 | 0.172 | 0.406 | 0.19 |
| Noz. Exit Wall Press., Low Thrust | psia | 0.026 | 0.016 | 0.022 | 0.037 | 0.019 |
| Total Flow Rate, Full Thrust | 1b/sec | 31.4 | 31.2 | 31.2 | 43.01 | 32.6 |
| Total Flow Rate, Low Thrust | 1b/sec | 4.2 | 3.2 | 3.7 | 4.06 | 3.26 |
| H ₂ Flow Rate, Low Thrust | 1b/sec | 0.600 | 0.457 | 0.74 | 1.35 | 0.466 |
| H ₂ Flow Rate, Full Thrust | 1b/sec | 4.49 | 4.46 | 4.46 | 6.00 | 4.66 |

presented in Ref. 13. Startup transient, main stage operation, and shutoff transient behavior of the O/F ratio for the ARCE-R engine at 10 percent and full thrust are shown in Fig. 18, along with the temporal response of the fuel flow rate at full thrust. Transient, startup and main stage operational data for the RL10-A-3-3A are shown in Fig. 19; detailed shutdown transient data were unavailable for the RL10 engine, other than the manufacturer's specification that on shutdown fuel is vented overboard, with a maximum of 0.25 lb total throughput of H_2 flowing through the engine nozzle.

The cross-hatched areas on Figs. 18 and 19 correspond to times during which the engine O/F ratio drops below 2.0, i.e., times during which a potential hazard exists with J-57 turbojet engine exhaust as the diffuser/ejector facility driving medium (as discussed previously in Section 3.3.2). Figure 20 emphasizes the potential startup and shutdown transient hazards which could occur if the J-57 turbojet engine exhaust were used as the driver during the transients: H_2 concentrations in the flow leaving the second stage would be well above the lower detonation limit, with or without reaction in the diffuser; additionally, static temperatures at Mach 2 would be too low during portions of the startup and shutdown to ensure reaction as the gases mix - resulting in potential detonatable mixtures which could be set off by complex shock structures, hot spots or accidental means such as an electrical discharge. For this, and the previously reviewed reasons, operation during startup and shutdown transients will use inert, gaseous nitrogen as the driving medium.

3.3.4 Space Engine Transient Hazard Assessment and Control

Combining the hazard control analysis (Section 3.3) with the transient characteristics of the space engines considered (Section 3.3.3) results in the transient hazard assessment synopsis in Table 6. For both engines a potential hazard is identified during startup and shutdown transients. The proposed control to eliminate these hazards is to use a purge GN_2 flow as

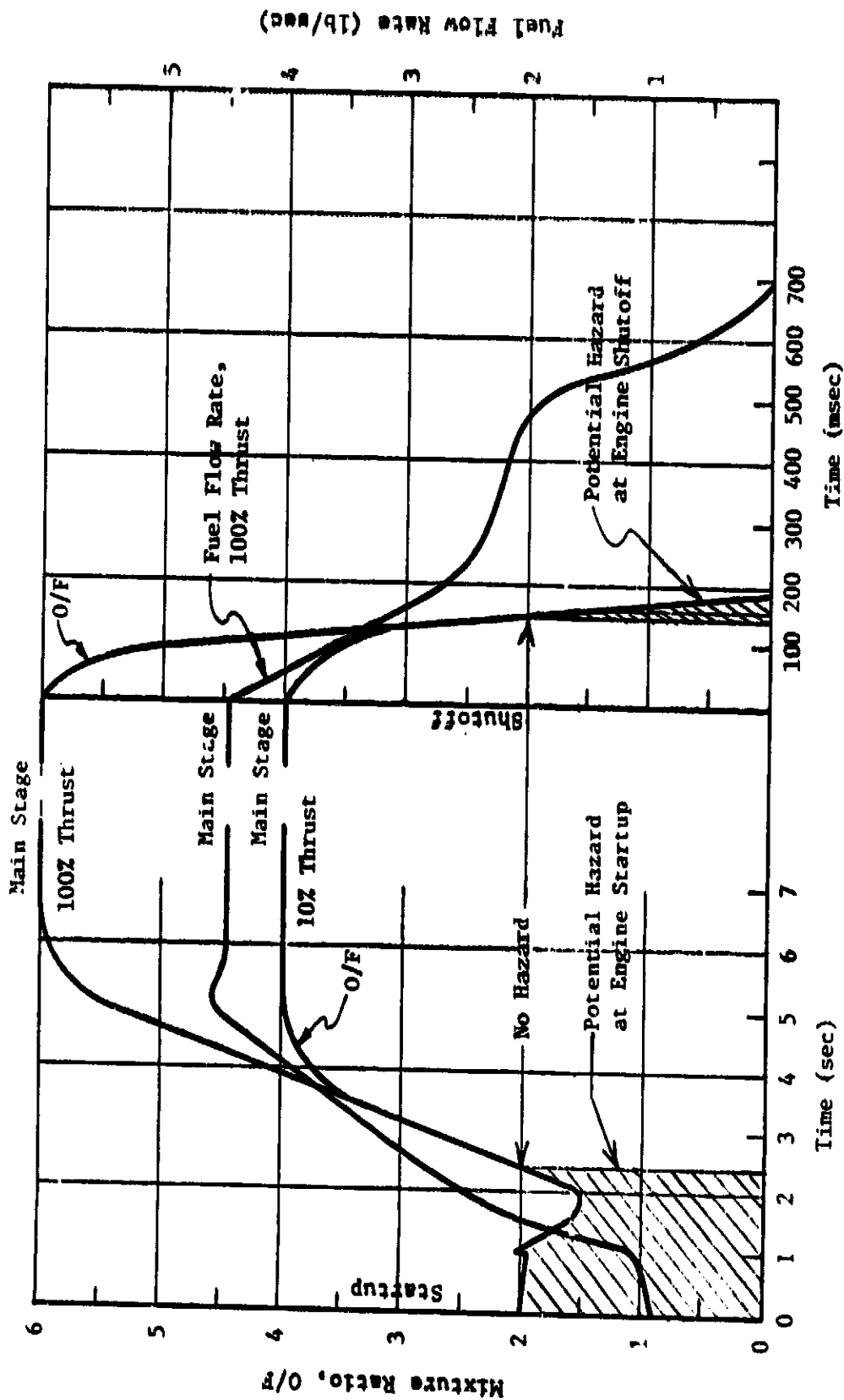


Fig. 13 AECE-R Engine Transient Characteristics (Estimated from ASE Engine Data, Refs. 11 and 12)

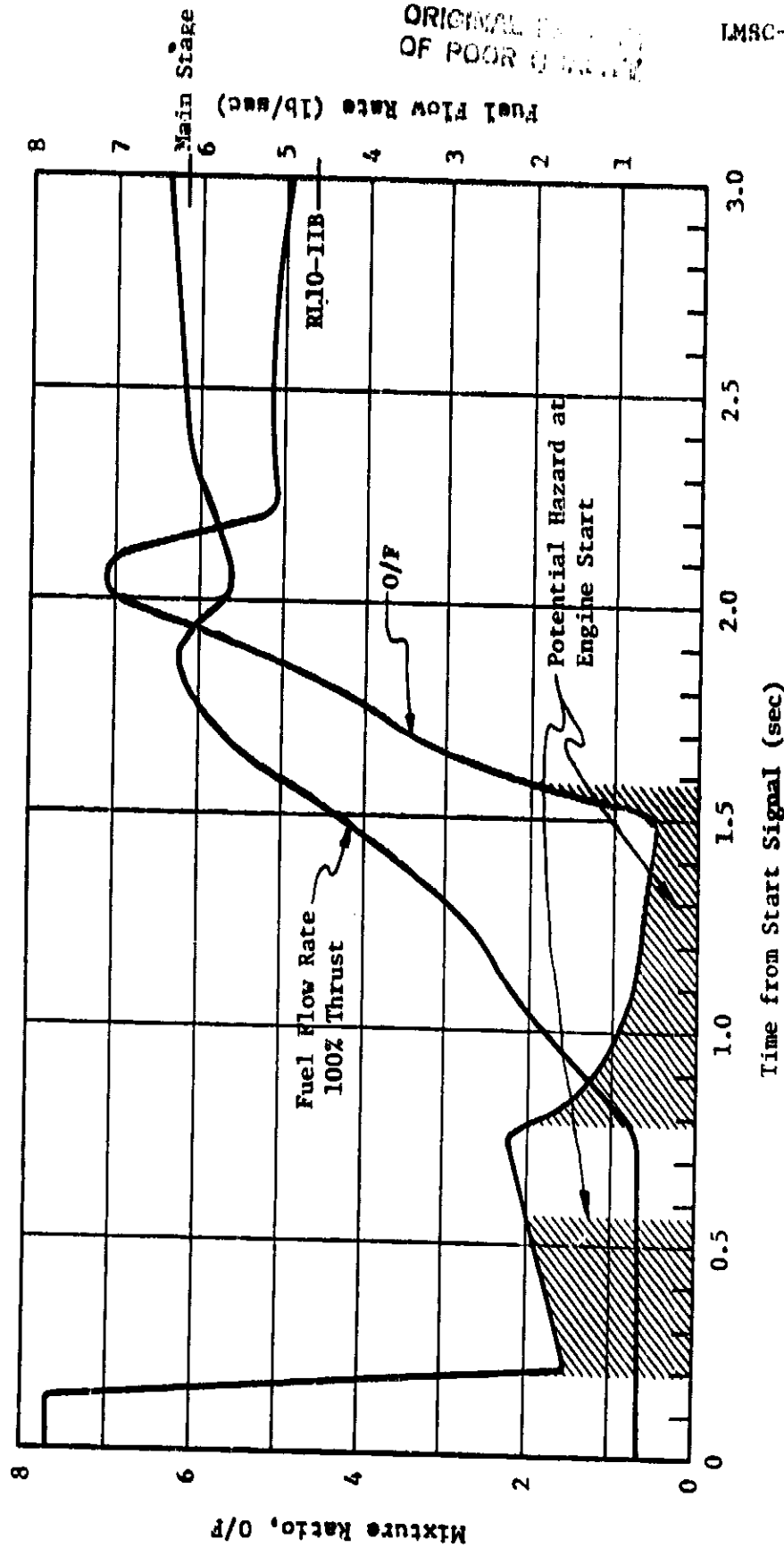


Fig. 19 RL10A-3-3A Engine Start Transient Characteristics (Ref. 13)

(Note: J-57 Turbojet exhaust will not be used as driver during transients.)

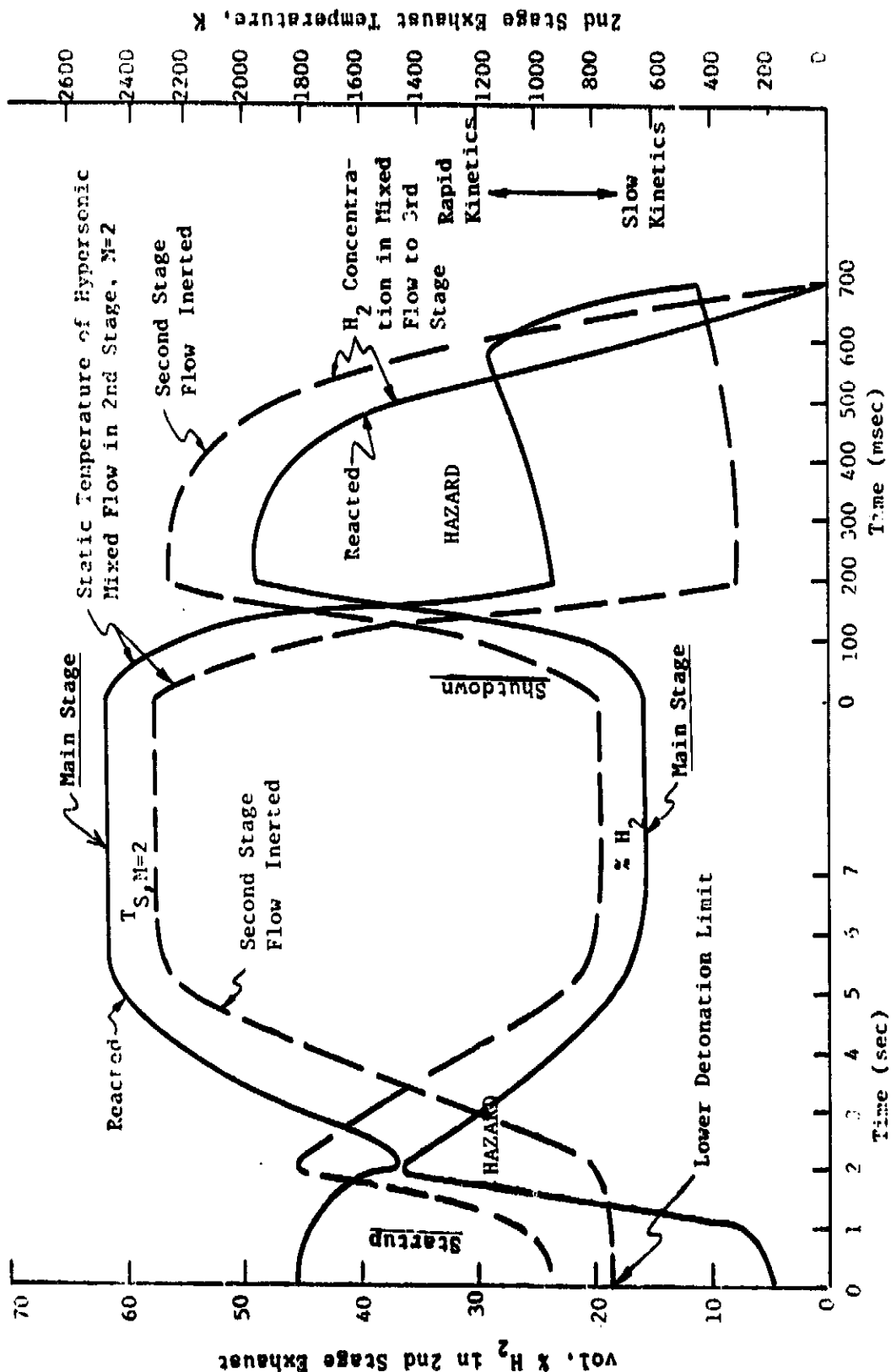


Fig. 20 AECE-R Engine Second Stage Diffuser Transient Characteristics
with J-57 Jet Engine Exhaust as Driver (26 lb/sec)

the inert gas driver in the first and second stages during transients, as required. No hazard exists during main stage engine operation.

Table 6 SYNOPSIS OF ENGINE TRANSIENT HAZARD ASSESSMENT

(DIFFUSER DRIVER: J57 JET ENGINE EXHAUST)

AECE-R Engine (Based on ASE Engine Data)

- Startup - Potential Hazard, O/F < 2.0 from 0 to 2.4 sec After Start Signal
- Main Stage - No Hazard, O/F = 6.0, High Thrust; O/F = 4.0, Low Thrust
- Shutdown - Potential Hazard; O/F < 2.0 at Shutoff Signal + 150 msec

RL10-IIB Engine (Based on RL10A-3-3A Engine Data)

- Startup - Potential Hazard; O/F < 2.0 from 0.20 to 1.58 sec after Start Signal
- Main Stage - No Hazard; O/F = 6.0 for Low and High Thrust Operation
- Shutdown - Potential Hazard; Quantitative Transient Data Inputs are Required.

Pratt & Whitney Inputs on RL10 Shutdown:

1. If a graphite nozzle is used, oxidizer-rich shutdown must be avoided to protect hot engine and red hot nozzle.
2. Somewhat in conflict with 1, H_2 is normally dumped overboard on shutdown, with a maximum total of 1/4 lb H_2 flowed through the nozzle on shutdown.

Proposed Control to Eliminate Potential Start/Stop Hazards:

Use a Purge GN_2 Flow as the Inert Gas Driver in 1st and 2nd Stages During Transients, as Required

Temporal response of the diluted, inerted flow leaving the second stage diffuser during 100 percent thrust AECE-R engine run transients with 150 lb/sec of GN_2 as the driving medium is shown in Fig. 21. As is evident, the hydrogen content of the exit stream is diluted well below the lower detonation limit for all times at which the mixture static temperature is significantly above room temperature. (A slightly higher flow of GN_2 -170 lb/sec-would ensure an overall H_2 concentration entering the third stage below the detonation limit even during the engine shutoff interval after 190 msec, after which time the oxidizer flow rate is negligible.)

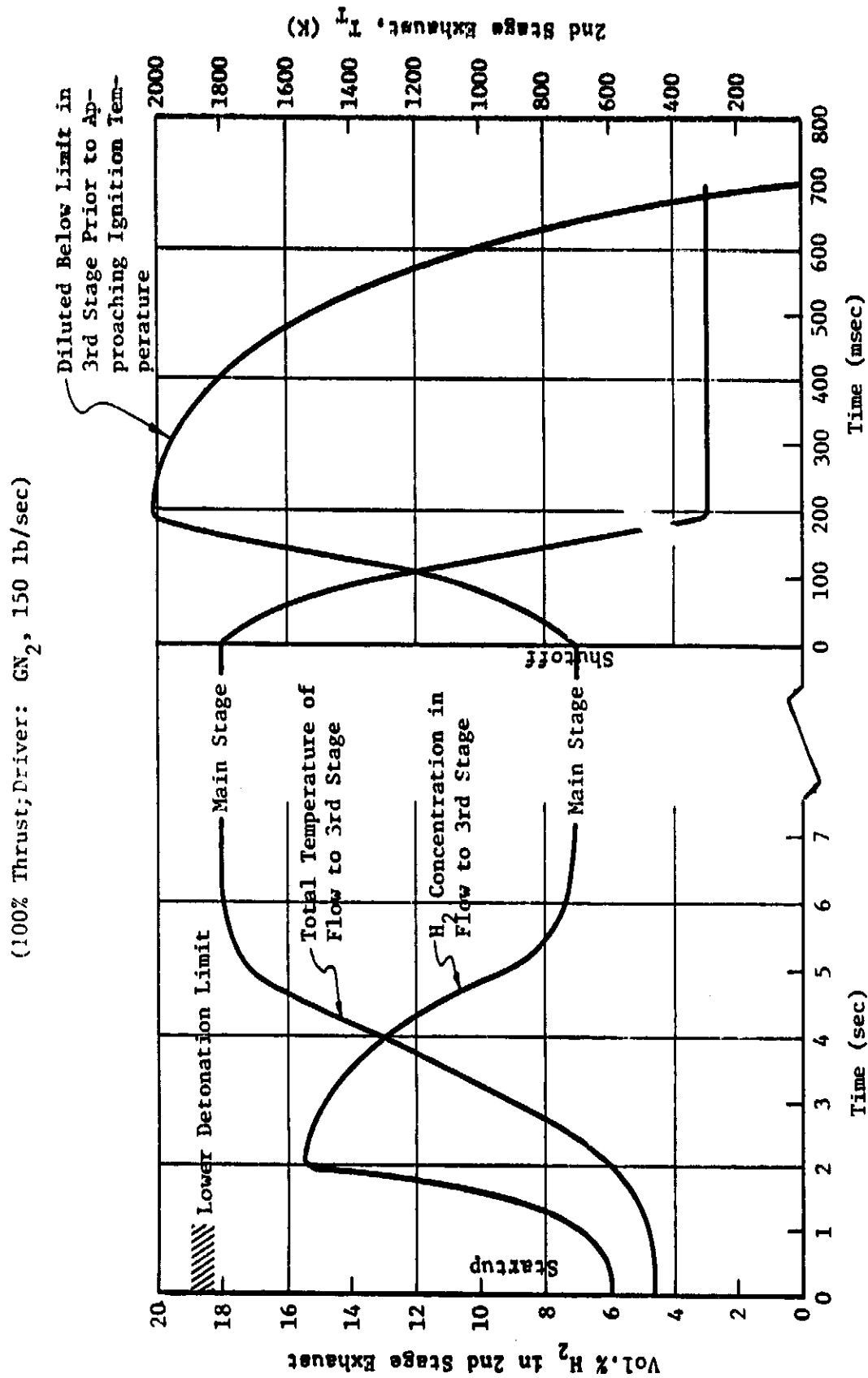


Fig. 21 AECE-R Engine Second Stage Diffuser Transient Operation

Main stage operation of both engines at low and full thrust is summarized for each stage in Tables 7 and 8, respectively, for both J-57 jet engine exhaust and GN_2 driving mediums. In all cases, with the stages being driven by the jet engine's exhaust, excess H_2 is progressively burned at high temperature and the flow ultimately leaves the facility with negligible residual hydrogen. With GN_2 driving the stages: (1) at low thrust, H_2 is diluted in the first two stages to a safe 2.8 or 8.5 percent in the two engines, with a second stage exhaust total temperature of only 955 or 958 K; in the third stage the mixture is further diluted, resulting in a near zero exhaust H_2 concentration of only 0.3 or 0.9 percent from the facility, assuming no further combustion, or to zero if combustion is completed in the third stage; (2) at full thrust, H_2 is diluted in the second stage to a safe 7.4 or 7.1 percent, but at a high total temperature of 1855 or 1806 K; in the third stage combustion continues at high temperature with a resultant negligible H_2 content in the facility effluent. Thus for the vast majority of test operation virtually no H_2 is discharged from the facility, and there is no requirement for an external torch to burn residual H_2 .

As discussed previously, start/stop transients are to be controlled by GN_2 flow to the first two stages such that the peak H_2 concentration in the flow entering the third stage is maintained below the lower detonation limit. At low thrust, with 50 lb/sec GN_2 driving the first two stages, the full main stage cold flow of H_2 can be controlled, as also is shown in Table 7. At high thrust, with 150 lb/sec GN_2 driving the first two stages, about 60 percent of the full main stage cold flow of H_2 can be controlled. Thus in the event of a stuck oxidizer valve on startup, provision of an automatic engine shutdown prior to reaching 60 percent of the full rated H_2 flow is required. Alternatively the full thrust transient GN_2 driver flow can be uprated to 250 lb/sec, if a full rated H_2 cold flow requirement is needed for engine acceleration or other tests.

Table 7 LOW THRUST OPERATION

| Engine Status | Driver (Stages 1 & 2) | Stage | RL10-IIB Engine Exhaust | | AECE-R Engine Exhaust | | Minimum P_{static} (psia) |
|-----------------------|---|--|-------------------------|-------------|-----------------------|-------------|-----------------------------------|
| | | | T_T , K | Vol.% H_2 | T_T , K | Vol.% H_2 | |
| Main Stage Burn | J-57s | Engine | 2958 | 29.5 | 2756 | 48.6 | - |
| | | 1 | 2628 | 16.9 | 2565 | 33.2 | 0.7 |
| | | 2 | 1968 | 0.1 | 2310 | 1.3 | 4.2 |
| | | 3 | 871 | N11 | 926 | N11 | 17.6 |
| | • H_2 is burned virtually to completion in first and second stages. | | | | | | |
| Main Stage Burn | GN ₂ (50 lb/sec) | Engine | 2958 | 29.5 | 2756 | 48.6 | - |
| | | 1 | 2461 | 15.4 | 2304 | 33.1 | 0.7 |
| | | 2 | 958 | 2.8 | 955 | 8.5 | 4.2 |
| | | 3 | 799- 825 | 0.3- N11 | 799- 878 | 0.9- N11 | 17.6 |
| | • Flow enters third stage with H_2 well below detonation limit. | | | | | | |
| Start/Stop Transients | GN ₂ (50 lb/sec) | Worst Cases: RL10-IIB Engine: Full Fuel Flow, 0.466 lb H_2 /sec AECE-R Engine: Full Fuel Flow, 0.74 lb H_2 /sec | | | | | |
| | | Engine | 300 | 99.8 | 300 | 99.8 | |
| | | 1 | 300 | 56.5 | 300 | 67.3 | |
| | | 2 | 300 | 11.5 | 300 | 17.1 | |
| | • H_2 flow is diluted with GN ₂ to below the detonation limit in stages 1 and 2. The full maximum rated cold H_2 flow at low thrust can be controlled. | | | | | | |

Table 8 100 PERCENT THRUST OPERATION

| | | | RL10-IIB Engine | | AECE-R Engine | | |
|--------------------------|---|--------|--------------------|----------------------|--------------------|----------------------|--|
| | | | Exhaust | | Exhaust | | |
| Engine Status | Driver (Stages 1 & 2) | Stage | T _T , K | Vol.% H ₂ | T _T , K | Vol.% H ₂ | Minimum P _{static} (psia) |
| Main Stage | J-57s Not Driven | Engine | 2958 | 29.5 | 2958 | 29.5 | - |
| | | 1 | 2958 | 29.5 | 2958 | 29.5 | - |
| | | 2 | 2872 | 16.3 | 2869 | 15.8 | 6.5 |
| | | 3 | 1545 | Nil | 1519 | Nil | 14.0 |
| | ● H ₂ is burned as rapidly as it mixes in second and third stages. | | | | | | |
| Main Stage Burn | GN ₂ (50 lb/sec) Not Driven | Engine | 2958 | 29.5 | 2958 | 29.5 | - |
| | | 1 | 2958 | 29.5 | 2958 | 29.5 | - |
| | | 2 | 1855 | 7.4 | 1806 | 7.1 | 6.5 |
| | | 3 | 1324 | Nil | 1300 | Nil | 14.0 |
| | ● H ₂ flow is diluted with GN ₂ to well below detonation limit in second stage and burns as rapidly as it mixes in third stage. | | | | | | |
| Stop/Start Transients | GN ₂ (150 lb/sec) ● H ₂ flow is diluted and cooled with GN ₂ to below the detonation limit in second stage. Up to 60 percent of the full maximum rated cold H ₂ flow can be controlled. | | | | | | |

4. SUBSCALE DIFFUSER MECHANICAL/STRUCTURAL DESIGN

The subscale ejector/diffuser system described in Section 3 of this report has been designed. The design details are discussed in this section.

4.1 GENERAL DESCRIPTION

The facility shown in LMSC Drawing R82734 is designed to flow non-combusted H_2 gas through a 650:1 area nozzle into a three stage ejector/diffuser system. The facility will consist of a H_2 chamber, throat, 650:1 area ratio nozzle, altitude cell, H_2 diffuser tube, and the three stage ejector/diffuser system. The altitude cell is designed to be pumped by the H_2 nozzle flow to maintain the required cell pressure during the H_2 flow tests. The ejector expansion area ratio is designed to be adjustable by varying the ejector throat area while maintaining a constant exit area. This is accomplished by translating the outer ejector throat and nozzle surface relative to the fixed inner ejector surface. The outer movable ejector surface is allowed to translate fore and aft being held in position radially by either a three or four pipe support system. By necessity, the third stage ejector has a four pipe support system while the first and second stage ejectors have a three pipe support system. The details of the three pipe support system are shown on LMSC Drawings R82737 and R82738. The ejector outer surface is translated using four equally spaced electrical actuators.

The actuators are capable of handling 5000 lbf each and have a 3 in. stroke for the first and second stage ejectors and a 6 in. stroke for the third stage ejector. The actuator details are not available at this time, although several suppliers are available. The first and second stage ejector throat areas are designed to be completely closed off and inerted

with GN_2 . The diffusers for the first and second stage ejectors are the efficient "second throat type" diffuser design. The third stage ejector is designed to be "started" and run by itself utilizing all of the turbojet exhaust. This ejector is designed to keep the pumped flow subsonic for better pressure recovery. Start-up should not be a problem since the ejector flow will be exhausting into a duct at an initial pressure of approximately 14.7 psia, thereby effectively limiting the ejector area expansion ratio. A few milli-seconds later, after the ejector has evacuated the upstream duct system the cell pressure will drop to 1.0 psia, and the ejector will operate at an area expansion ratio of 3.1:1.0.

The facility will be mounted on the existing rail and support system located at MSFC's Cold Flow Calibration Facility adjacent to the Hot Gas Facility, Building 4554. The site plan is shown in LMSC Drawing R82733. The plan and elevation view is shown in LMSC Drawing R82732. The ejector inlet piping from the J-57 turbojet engine is shown in planform view in LMSC Drawing R82736. The J-57 piping details other than those shown in R82736 were beyond the scope of this contract as mentioned previously in Section 2. The facility will not require cooling water.

The facility also consists of: (1) a J-57 turbojet engine and its fuel tank and controls; (2) the gaseous hydrogen system (piping and components) and high pressure GN_2 supply lines; (3) overhead hoist system for materials handling; (4) hydrogen leak detectors; (5) remote control Firex system; (6) TV camera surveillance system and communication system; (7) remote control systems from Building 4554; and (8) an instrumentation system with remote readout in Building 4588.

4.2 GOVERNMENT-FURNISHED EQUIPMENT LIST

It was beyond the scope of this contract to develop a detailed GFE list. The following list of GFE equipment required to support this facility is preliminary:

1. One working J-57 turbojet engine complete with fuel tank, starter system, instrumentation, and controls
2. One J-57 turbojet engine support structure
3. Approximately 100 ft of 5 in. GN₂ supply line to the present site from the northeast side of Building 4548 and shutoff valve with downstream bolt flange connection to flow 73 lb/sec
4. Gaseous hydrogen trailer and control system with 1 in. pipe type AN flared fitting for attachment to the facility to flow 0.5 lb/sec
5. A low pressure (150 psig) GN₂ purge line system to flow 2 lb/sec
6. Facility instrumentation system with remote readout in Building 4588
7. Overhead hoist or ground support equipment for materials handling
8. Hydrogen leak detector system
9. Remote controlled Firex system
10. TV camera surveillance system and communication system, and
11. Computer system for remote control and data reduction and plotting.

4.3 MATERIALS AND COMPONENTS SELECTION

The subscale ejector/diffuser facility will be constructed of 304L stainless steel except as noted. The turbojet exhaust ducting will be constructed of 321 stainless steel of 0.060 in. thickness except for the flanged connections which will be thicker. All flange gaskets will be Sepco Grafoil crinkle gasket tape style SG6360. The 1/4 in. by 1/4 in. ejector sliding seals will be fabricated from Sepco Grafoil sheet style SG36 of 0.015 in. thickness. A local supplier of the Sepco products is TENN-VAL, Inc., of Decatur, Alabama. The full ported check valve is AGCO model CV-2 supplied by the Blythe Company, Indian Trail, N.C. The Digicell valves are supplied by Horton Instrument Company, Birmingham, Alabama. The EMCV valve, the electromechanical actuator, and thermal expansion joints will be custom made for this facility.

The thermal expansion joints shown in LMSC Drawing R82736 can be supplied by U.S. Bellows, Santee, California. The electromechanical control valve (EMCV) and the electromechanical actuator specifications and possible suppliers are listed below.

Electromechanical Control Valve (EMCV) Specifications

| | |
|--|--|
| Opening Time | 100 msec |
| Actuator: | |
| Solenoid with pressurized GN ₂ over hydraulic | |
| GN ₂ pressure available: | 4000 psig |
| Hydraulic pressure available: | 2500 psig |
| Hydraulic flow available: | 35 gpm |
| Valve Type: | Butterfly |
| Operating Environment | |
| Temperature: | 940 F |
| Pressure | 18 psig |
| Supplier: | The Blythe Company, Indian Trail, N.C. |

Electromechanical Actuator Specifications

| | |
|---|---|
| Maximum Operating Force | 5000 lbf |
| Operating Voltage | 28 Vdc |
| Stroke Speed | 3 in./min. |
| Stroke | |
| First and Second Stage Ejector | 3 in. |
| Third Stage Ejector | 6 in. |
| Dimensions: | |
| Closed Length | 10 in. |
| Outside Diameter | 6 in. |
| Environment: | |
| Ambient plus capability of being inerted using GN ₂ purge to eliminate all explosion hazards | |
| Potential Suppliers: | Inland Motor, Radford, Va. |
| | Plessey Dynamics, Hillside, N.J. |
| | Clifton Precision, Clifton Heights, Pa. |

4.4 DRAWINGS

A detailed list of all the drawings which were developed for this facility under this contract is listed in Appendix C. Copies of the drawing set will be released at the discretion of Mr. K.E. Riggs, EP23, MSFC Contracting Officer's Representative.

4.5 STRESS ANALYSIS

The detailed stress analysis of each facility drawing is contained in Appendix B. The factors of safety which were used are 1.6 on yield strength and 4.0 on ultimate strength. A safety margin summary is contained in Appendix B and shows that each part has an adequate margin of safety.

5. PLANS

Under this contract, a Preliminary Test Plan, an Instrumentation Plan, and a System Operating Procedure Plan were developed. The preliminary test plan was published under separate cover as Ref. 14. The Instrumentation and Operational Procedures Plans are described in this section.

5.1 INSTRUMENTATION PLAN

The subscale ejector/diffuser facility is shown in Fig. 1. The first stage ejector will operate at the highest duct-to-ejector-throat-area ratios, the second stage ejector will operate at medium ejector area ratios and the third stage ejector will operate at the lowest ejector area ratio. The range of ejector area ratios will be between 3 and 300 considering the full scale design. The purpose of the subscale test is to obtain an experimental data base in a subscale facility which when combined with the analytical models, will yield an empirical data base to define completely the operational data base for high volume, low pressure ejector systems such that a full scale design can be accomplished. The subscale data will define the ejector blank-off capability and pumping capability as a function of ejector-to-secondary mass-flow ratio, ejector driving pressure, and ejector area ratio. Data will be obtained from all three ejector stages and will span the ejector area ratio range from 4 to 300, ejector driving pressure range from 4 to 40 psia, and ejector mass flow ratios from 3 to infinity. The variables which will be measured will be cell pressure, ejector exit and duct pressures, exit static and total pressure, the ejector driving total pressure, the driven mass flow rate (secondary), the ejector mass flow rate, and the ejector throat area. The ejector throat area will be calibrated as a function of ejector axial position. The preliminary test matrix configurations and the test matrix were developed in the test plan (Ref. 14).

The following is a preliminary list of the instrumentation required to conduct the test.

1. J-57 turbojet engine instrumentation as called out in Ref. 15.
2. Flow measuring devices
 - a. J-57 air flow data taken by means of a smooth approach inlet mounted on the engine fitted with static and total pressure rakes as defined in ASHAE Fan Test code.
 - b. J-57 fuel flowmeter
 - c. One 0.5 in. diameter sharp edge orifice to measure the altitude cell GN₂ purge
 - d. One 1 in. diameter venturi meter to measure the GH₂ flow
 - e. One 3 in. diameter Digicell flow and pressure control valve to measure the first stage ejector mass flow
 - f. One 24 in. diameter venturi meter to measure the second stage ejector J-57 mass flow
 - g. One 5 in. diameter Digicell flow and pressure control valve to measure the second stage ejector GN₂ flow rate
3. 150 pressure transducers to record pressures throughout the facility
4. Fifty temperature measurement locations throughout the facility
5. Digicell control computer.

Locations of all instrumentation/measurements will be specified during the next phase of the facility development. Drawing No. R82716-1, "Nozzle Piece, First Stage," shows typical instrumentation port (pressure) and thermocouple attachment details.

5.2 OPERATIONAL PLAN

The operational procedure plan will be developed more completely as the facility construction progresses. The preliminary operational plan follows assuming a diffuser/ejector test using gaseous H₂.

5.2.1 Pretest

1. Photograph the facility.
2. Verify that the J-57 fuel tank level is adequate.
3. Verify that the GN₂ pressure is satisfactory.
4. Verify that the GH₂ trailer pressure is satisfactory.
5. Connect instrumentation.
6. Verify that the test instrumentation has been installed per instructions of Test Request Sheet and the Run Time and Test Conditions annotated on the TCP.
7. Schedule the ejector/diffuser test.
 - a. () GN₂ as needed
 - b. () GH₂ as needed
 - c. () Photography
 - d. () Closed Circuit TV
 - e. () Instrumentation
 - f. () Control.

5.2.2 Test Day

1. Verify that the instrumentation and controls are ready for the X-1 hour announcement.
2. Make the X-1 hour announcement.
3. Verify that all ground support equipment is parked and that power is OFF.
4. Check out test stand for proper electrical power.
5. Activate GN₂ system per procedure.
6. Set the following pressure regulators to the proper pressures.
 - a. GN₂
 - b. GH₂
 - c. GH₂ line purge.

7. Set the ejector throat areas in accordance with test request sheet.
8. Activate hydraulic system per procedure.
9. Cycle all valves to verify satisfactory operation.
10. Check that all J-57 engine controls are operating satisfactorily.
12. Verify that cutoff checks are satisfactory.
13. Verify that sequence test has been conducted per procedure.
14. Verify that TV monitors are functioning properly.
15. Verify that video recordings for TV are ready.
16. Activate the J-57 starter air system.
17. Activate the Firex system.
18. Verify that GH_2 leak detectors are active.
19. Verify that data system and controls are ready for X-30 minutes.
20. Give X-30 minute warning announcement.
21. Activate the GH_2 system per procedure.
22. Set up road blocks at test stand.
23. Make X-15 minutes announcement. (Close HGF area to all personnel.)
24. Verify duration timer set at (TBD) second and power switch ON.
25. Intercom tape ON.
26. Open the GH_2 main shutoff.
27. Prepare the GN_2 system for test.
28. Prepare the J-57 control system for test per procedure.
29. Make the X-10 minutes warning announcement.

30. Prepare the GH₂ system for test.
31. Turn data system ON - SLOW
32. Turn video recording ON
33. Adjust the ejector GN₂ flow controller
34. Adjust the GH₂ flow controller.
35. Make X-5 minute warning announcement.
36. Verify that the following systems are ready:
 - a. Control
 - b. Data system
 - c. Cameraman
 - d. Analog recorder, and
 - e. Test stand.
37. Cutoffs ready - ON
38. Sound X-20 second siren.
39. Set J-57 data systems on FAST
40. Give firing command.
41. Start J-57 engine per procedure.
42. Verify J-57 operation at IDLE power setting.
43. Allow J-57 warmup time.
44. Advance J-57 throttle position to TEST SET position; check J-57 operation per procedure.
45. Verify ejector system operation according to test request.
46. Conduct test per test request.
47. Cutoff
 - a. GN₂ purges - ON
 - b. Cameras - OFF
48. Deactivate the GH₂ system.
49. Deactivate the GN₂ system.

50. Clear the test stand for designated crew.
51. Turn intercom - OFF.
52. Turn data system - OFF.
53. Turn video recording - OFF.

5.2.3 On Stand Post-Test

1. Perform appropriate post-test check outs of instrumentation and J-57 engine.
2. Deactivate Firex system.
3. Deactivate hydraulics.
4. Reset pressure regulators to 0 psig.
5. Remove road blocks.
6. Make ALL CLEAR announcement.
7. Shut off electrical power to test stand.

5.3 SAFETY PLAN

5.3.1 Grounding Requirements

Grounding requirements for this facility are as specified in the "Safety Manual," AMCR-385-100, 21 April 1970, by Headquarters, U.S. Army Materiel Command, Washington, D.C. 20315, specifically under Section 8, page 8-20, "Tanks and Towers."

5.3.2 Purge Requirements

Since this facility uses hydrogen, the purging requirements for electrical equipment and wiring will be as specified in KSC STD-E-002, Revision A, "Hazard Proofing of Electrical Equipment."

6. REFERENCES

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2. Gordon S., and B.J. McBride, "Computer Program for Calculation of Complex Chemical Equilibrium Compositions, Rocket Performance, Incident and Reflected Shocks, and Chapman-Jouguet Detonations," NASA SP-273, Interim Revision, March 1976.
3. Thoenes, J., A.J. McDaniel, A.W. Ratliff, and S.D. Smith, "Analysis of Chemical Lasers - Vol. 1 - Laser and Mixing Program LAMP - Theory and User's Guide," MLCOM Report RK-CR-74-13, Lockheed Missiles & Space Company, Huntsville, Ala., June 1974.
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5. Howell, R.R., "Experimental Operating Performance of a Single-Stage Annular Air Ejector," TN D-23, Langley Research Center, Hampton, Va., October 1959.
6. Drell, I.L., and F.E. Belles, "Survey of Hydrogen Combustion Properties," NACA Report 1383, April 1957.
7. "Development of RL10 Torch Ignition System," PWA FR-303, Pratt & Whitney Aircraft, West Palm Beach, Fla., November 1961.
8. Lewis B., and G. von Elbe, Combustion, Flames and Explosions of Gases, Academic Press, 1961, 2nd Edition.
9. Semenov, N.N., "Some Problems in Chemical Kinetics and Reactivity," Vol. II, Chapter X, translated by M. Boudart, Princeton University Press, Princeton, N.J., 1959.
10. Huber, P.W., C.J. Schexnayder, and C.R. McClinton, "Criteria for Self-Ignition of Supersonic Hydrogen-Air Mixtures," NASA TP 1457, August 1979.
11. Campbell, R.G., "Advanced Space Engine Powerhead Breadboard Assembly System Study," NASA CR-135232, Rockwell International Corporation/Rocketdyne Division, March 1978.

12. Martine, A., "ASE Shutdown Transients," Rockwell International Corporation, Letter to Fred Garcia, 9 December 1983, transmitting non-proprietary data to NASA.
13. "Preliminary Specification No. 2289: RL10A-3-3A Rocket Engine Atlas Centaur Installation Model Specification," United Technology, Pratt & Whitney Aircraft/Government Products Division, June 1981; also "Design Report for RL10A-3-3A Rocket Engine," same source, January 1982.
14. Wojciechowski, C.J., "Preliminary Test Plan for a Subscale Jet Engine Driven Ejector/Diffuser System," LMSC-HREC TM D867439, Lockheed Missiles & Space Company, Huntsville, Ala., 23 April 1984.
15. Pratt & Whitney Aircraft Specification No. A-1649-G for Model J57-P-19W Engine, dated 12 October 1955.

Appendix A
FULL SCALE GASDYNAMIC
SAFETY ANALYSIS

**DESIGN OF A SUBSCALE DIFFUSER
FOR HIGH EXPANSION RATIO
ENGINE TESTING**

**FULL SCALE GASDYNAMIC
SAFETY ANALYSIS**

by
C. J. Wojciechowski
S. C. Kurzius

13 April 1984














Missiles & Space Company, Inc.
Huntsville Research & Engineering Center

AGENDA

1. Objective
2. Milestones and Schedule
3. Concept of Preliminary Full Scale Design
4. Technical Issues and Concerns
5. Key Progress to Date
 - Analysis Shows Safe Operation
 - Design Meets All Requirements
6. Future Work

AMENDED SCOPE OF WORK SCHEDULE AND MILESTONES

| Task | Description | Months | | |
|------|--|--|---|---|
| | | Feb | Mar | Apr |
| A | Full-Scale Design Analysis |  | | |
| B | Full-Scale Gas Dynamic Hazard Analysis |  |  | |
| C | Full-Scale Ejector Analysis | |  | |
| D | Subscale Design Recommendation | |  | |
| E | Diffuser Sensitivity Analysis |  |  | |
| | Intermediate Reviews |  | |  |
| | 90% Design Review | | |  |
| | Final Report | | |  |

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OF POOR QUALITY

TECHNICAL ISSUES AND CONCERNS

- o Ejector Stability and Controllability
- o Transient Operation
- o Overall Ejector Performance
 - Scale Effects (Langley, MSFC Prototype - Full Scale)
- o Safety
 - Suppression of Hydrogen Detonation to be Evaluated by Analysis and Test Data
 - Facility to be Designed to Detonation Loads

SYNOPSIS OF ENGINE TRANSIENT HAZARD ASSESSMENT

(DIFFUSER DRIVER: J57 JET ENGINE EXHAUST)

AECE-R Engine (Based on ASE Engine Data)

- Startup - Potential Hazard, $O/F < 2.0$ from 0 to 2.4 sec After Start Signal
- Main Stage - No Hazard, $O/F = 6.0$, High Thrust; $O/F = 4.0$, Low Thrust
- Shutdown - Potential Hazard, $O/F < 2.0$ at Shutoff Signal + 150 msec

RL10-IIB Engine (Based on RL10A-3-3A Engine Data)

- Startup - Potential Hazard; $O/F < 2.0$ from 0.20 to 1.58 sec after Start Signal
- Main Stage - No Hazard; $O/F = 6.0$ for Low and High Thrust Operation
- Shutdown - Potential Hazard; Quantitative Transient Data Inputs are Required.

Pratt & Whitney Inputs on RL10 Shutdown:

1. If a graphite nozzle is used, oxidizer-rich shutdown must be avoided to protect hot engine and red hot nozzle.
2. Somewhat in conflict with 1, H_2 is normally dumped overboard on shutdown, with a maximum total of 1/4 lb H_2 flowed through the nozzle on shutdown.

Proposed Control to Eliminate Potential Start/Stop Hazards:

Use a Purge GN_2 Flow as the Inert Gas Driver in 1st and 2nd Stages During Transients, as Required

REVIEW

Primary Concern - Potential Hazard on Startup and Shutdown with Hot, H₂-Rich Engine Effluent Driven by Air-Rich Jet Engine Ejector Streams.

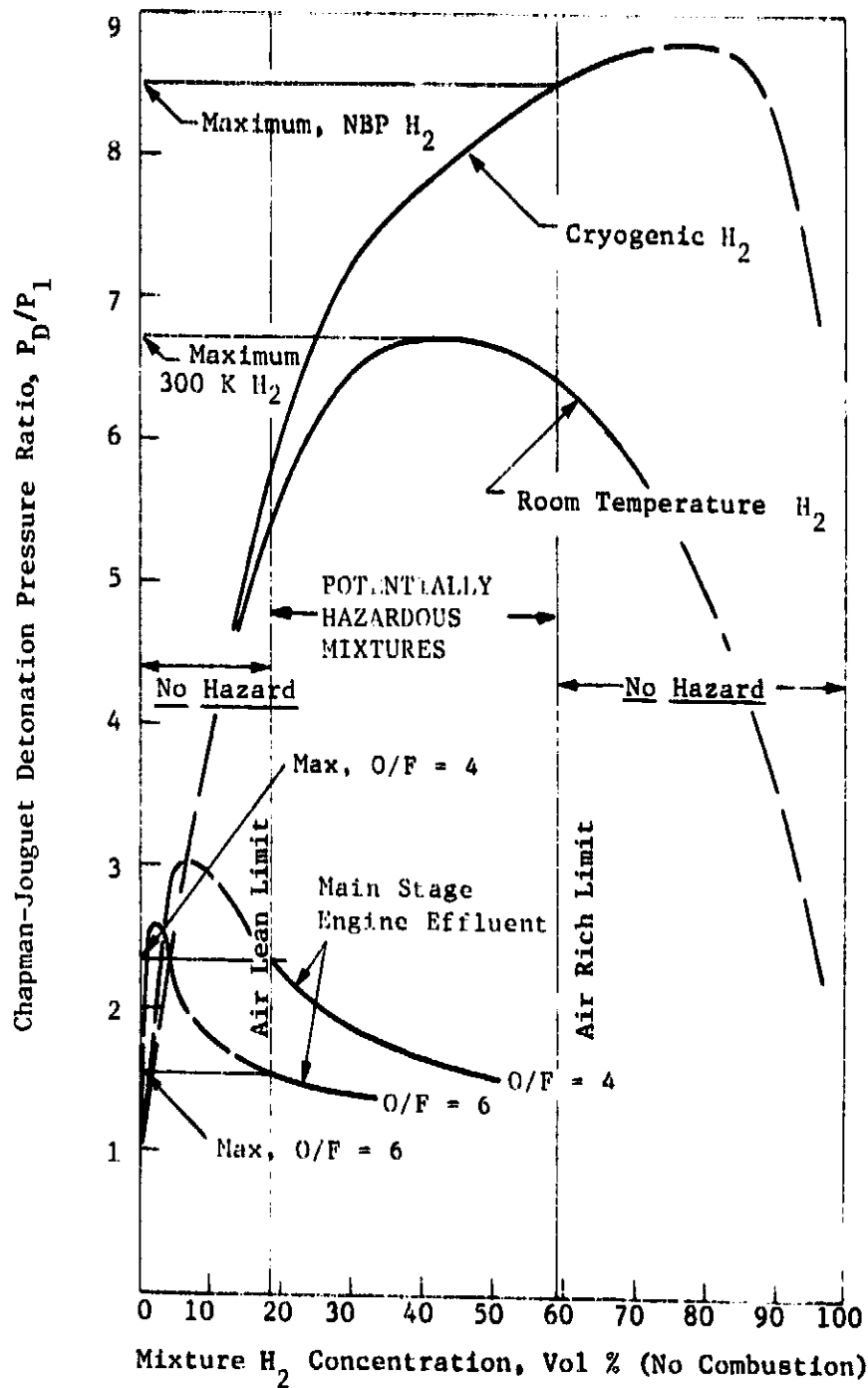
Analysis Path

- Review Engine Performance Data
- Initialize Diffuser Design for Engine Tests
- Evaluate Hazard
- Modify Design and Operation to Eliminate Hazard as Required

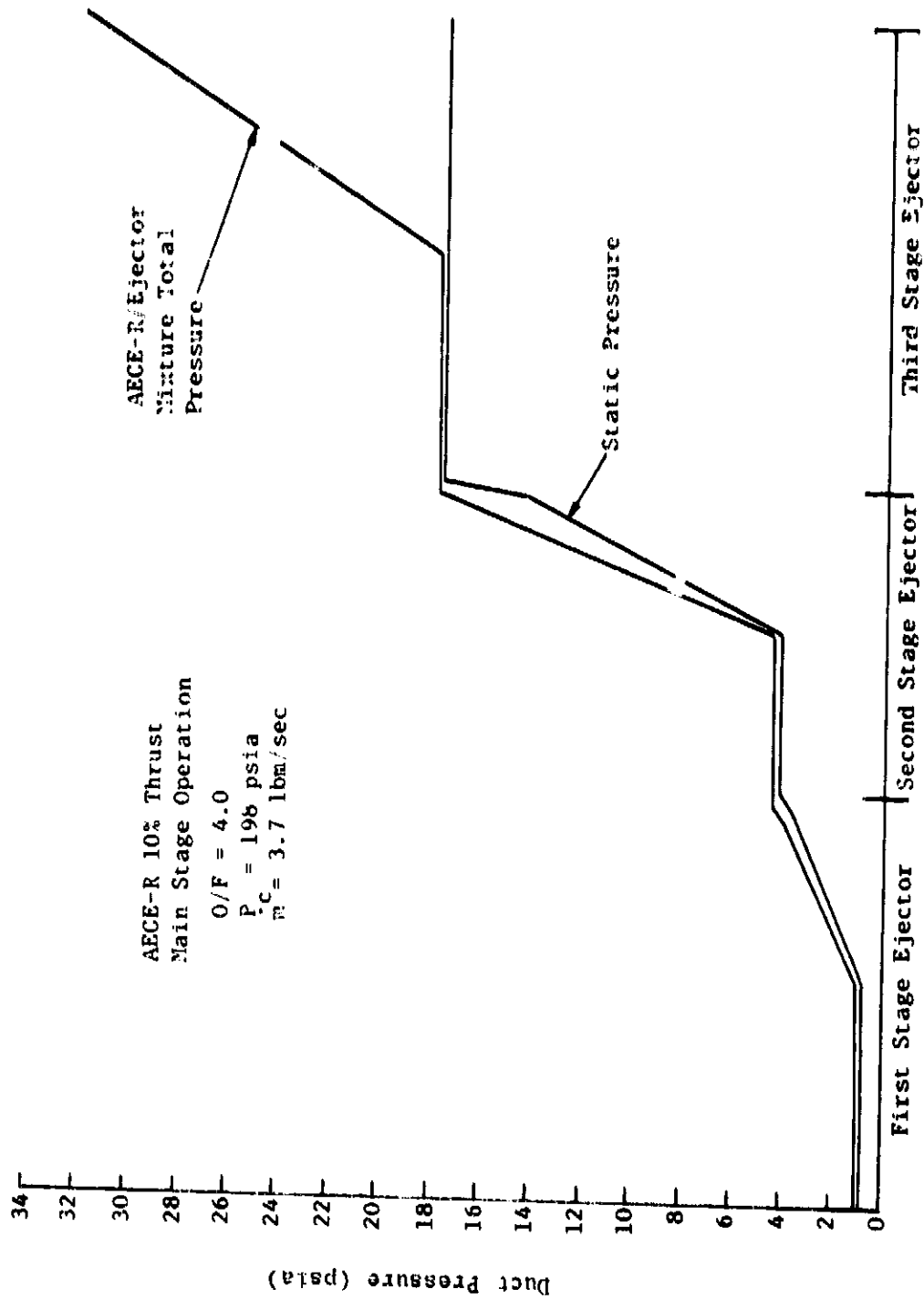
Space Engines Analyzed

- | | | |
|-------------|---|---------------------|
| • RL-10-IIB | } | 10% and 100% Thrust |
| • AECE-R | | |

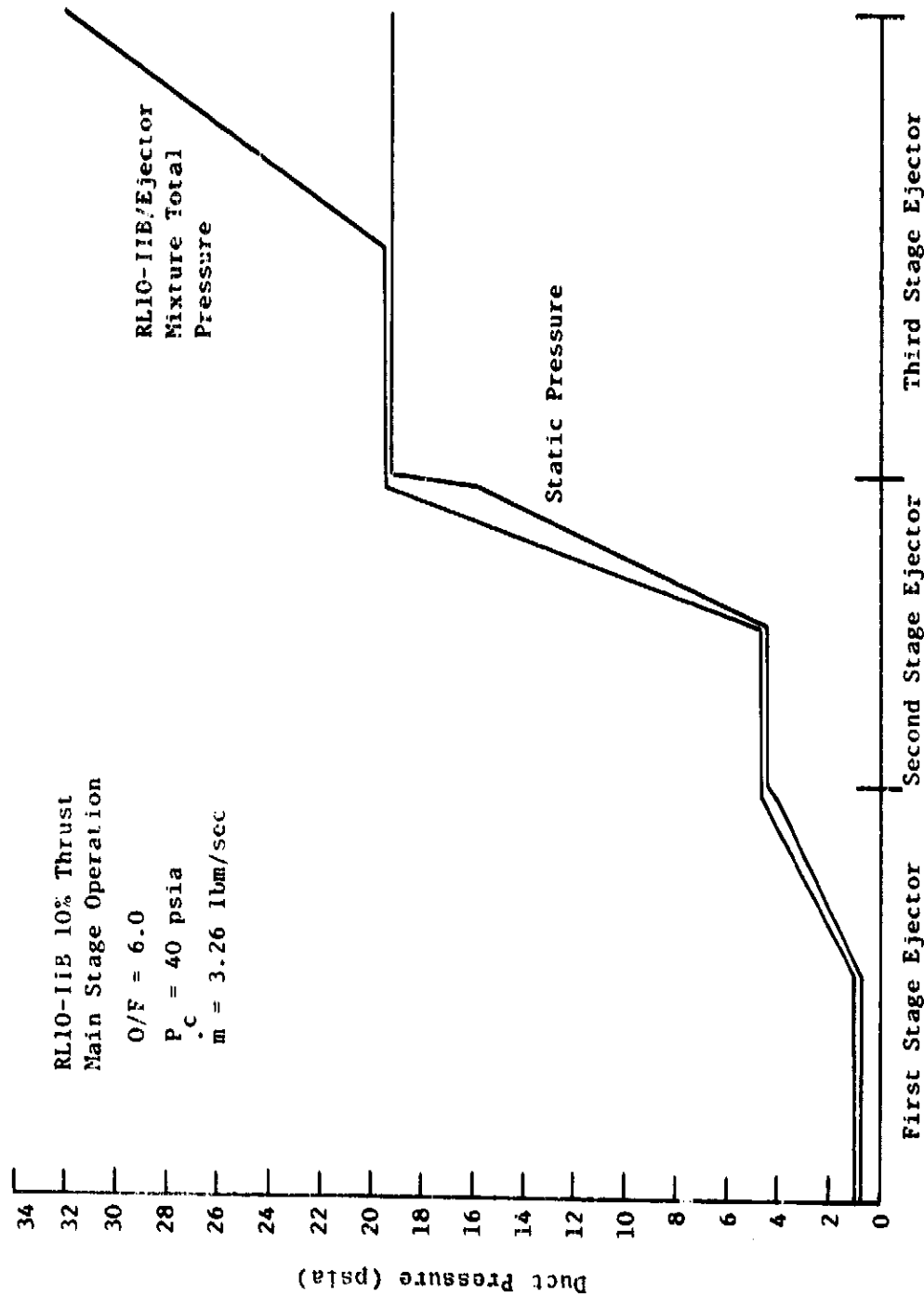
HAZARD ANALYSIS: WORST CASE
CHAPMAN-JOUQUET DETONATION PRESSURE RATIO
CHARACTERISTICS AT PREVAILING STREAM
TOTAL TEMPERATURES



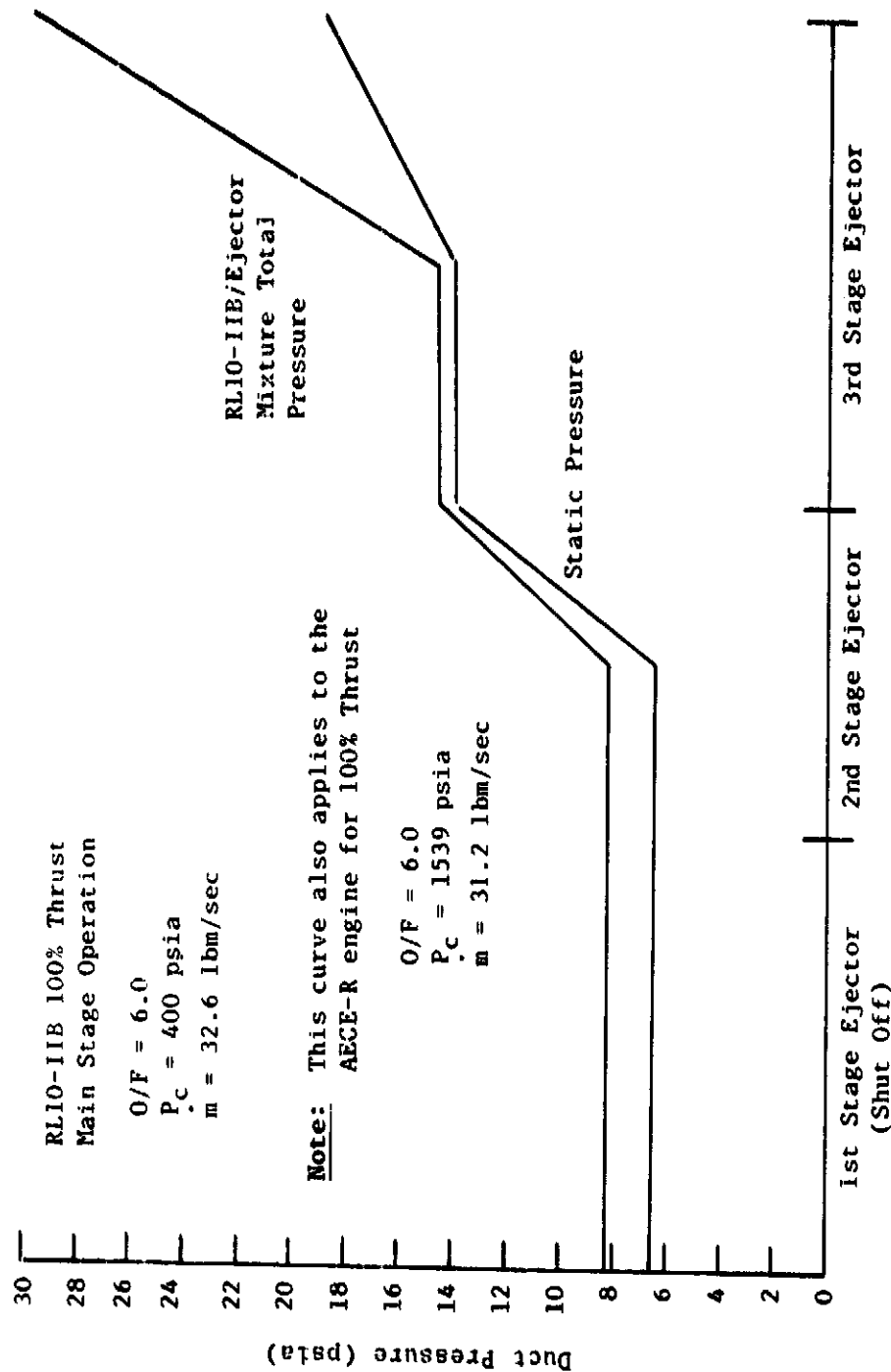
FULL SCALE AECE-R 10% THRUST DIFFUSER/EJECTOR PRESSURE DISTRIBUTION



FULL SCALE 10% THRUST DIFFUSER/EJECTOR PRESSURE DISTRIBUTION

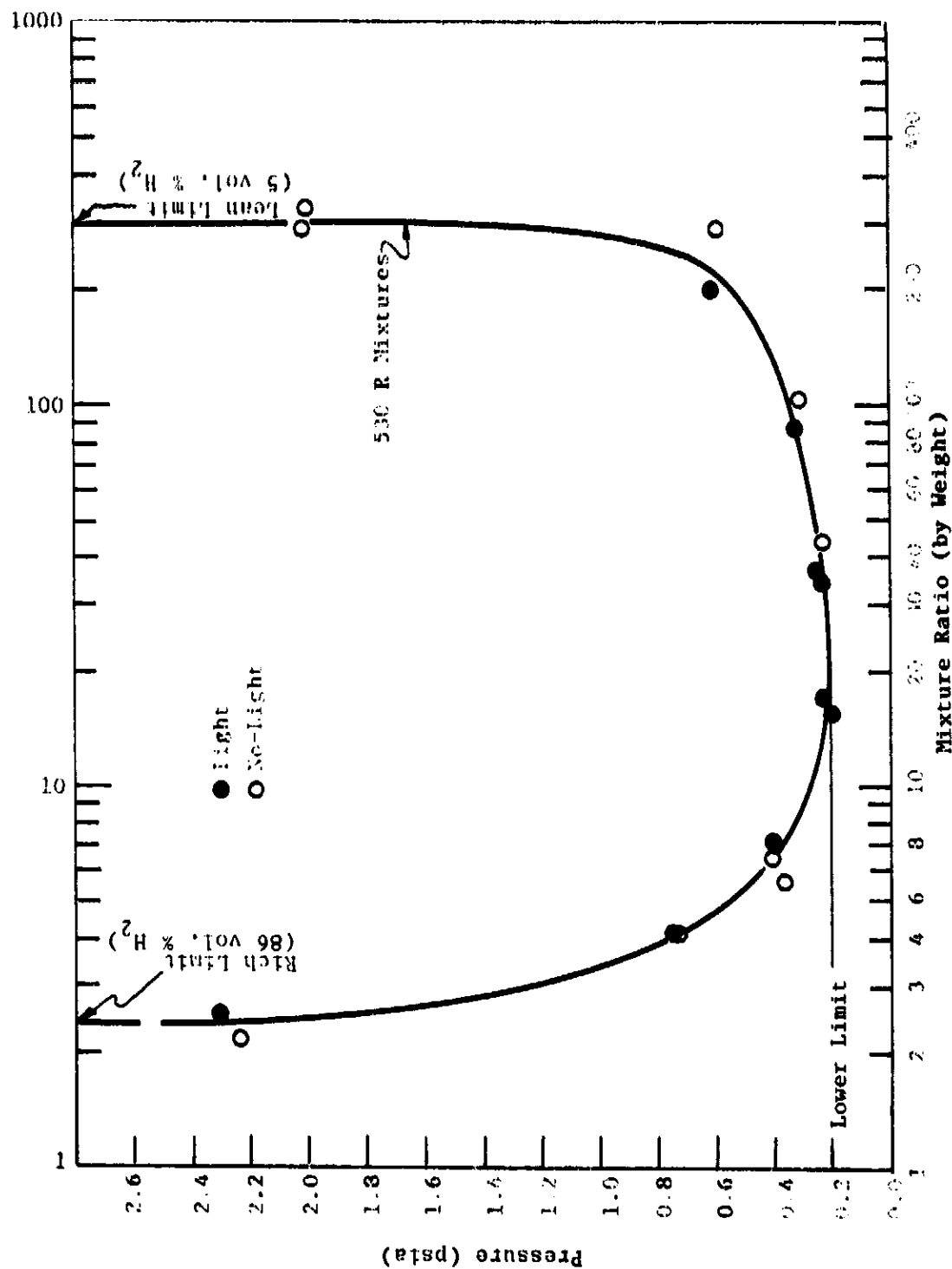


FULL SCALE RL10-IIB 100% THRUST DIFFUSER/EJECTOR PRESSURE DISTRIBUTION



H₂ -GOX STATIC IGNITION LIMITS

(Spark igniter, 4 in. diameter x 15 in. long chamber, PWA FR-303, Nov 61)



H₂-LOX ENGINE EXHAUST AUTOIGNITION CHARACTERISTICS

Fuel: H₂-Rich Space Engine Effluent

AFCE-R Engine: 3.7 lb/sec, Low Thrust
31.2 lb/sec, Full Thrust

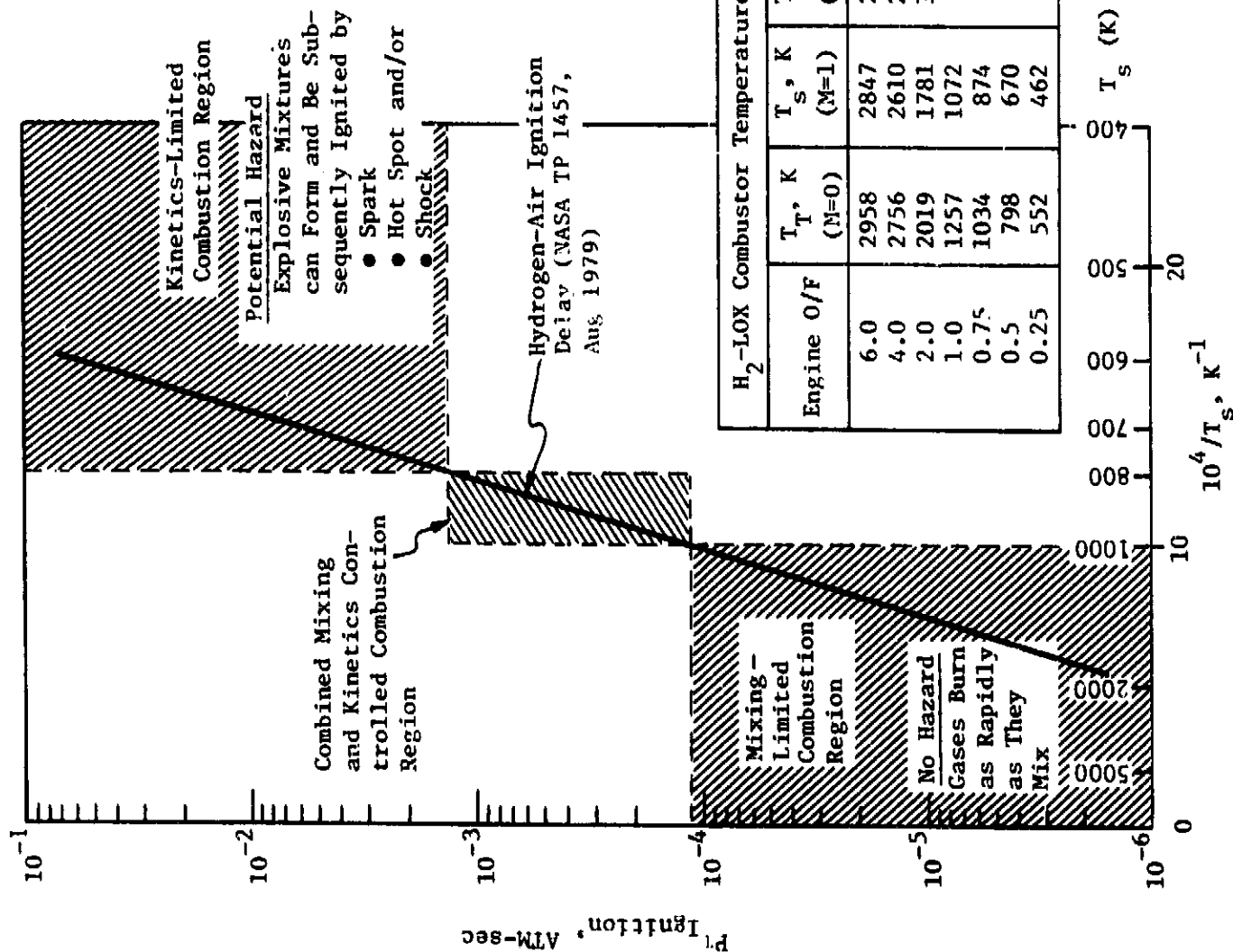
RL10-IIB Engine: 3.2 lb/sec, Low Thrust
32.6 lb/sec, Full Thrust

Oxidizer: J57 Jet Engine Exhaust: O₂:
16.7 vol.%; T₀=0: 778 K

1st Stage: 2.8 lb/sec (Low Thrust Only)

2nd Stage: 23.2 lb/sec: Low Thrust
26.0 lb/sec, Full Thrust

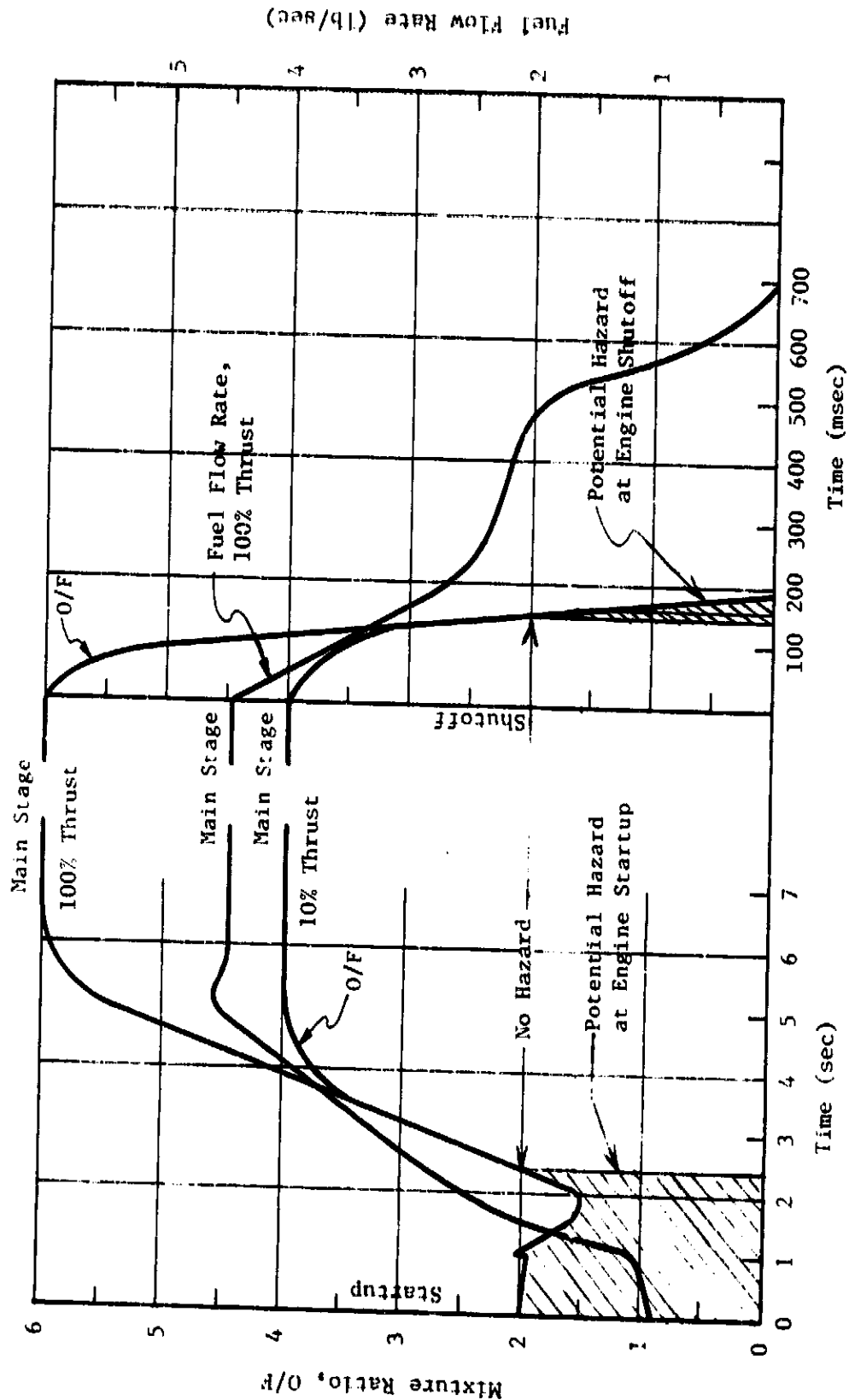
3rd Stage: 451 lb/sec: Low and Full Thrust



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OF 1000 PAGES

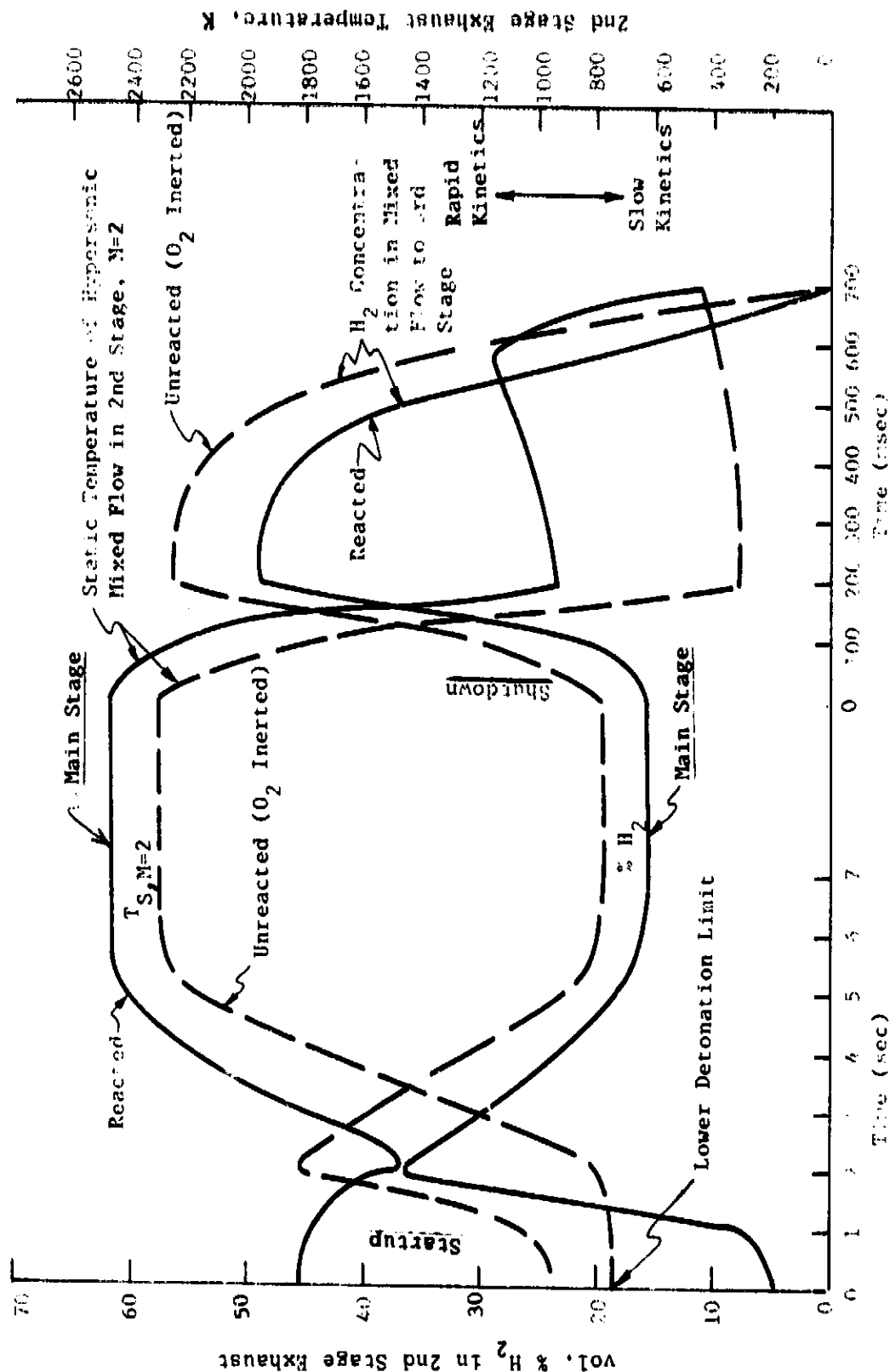
AECE-R ENGINE TRANSIENT CHARACTERISTICS

(Estimated from ASE Engine Data)

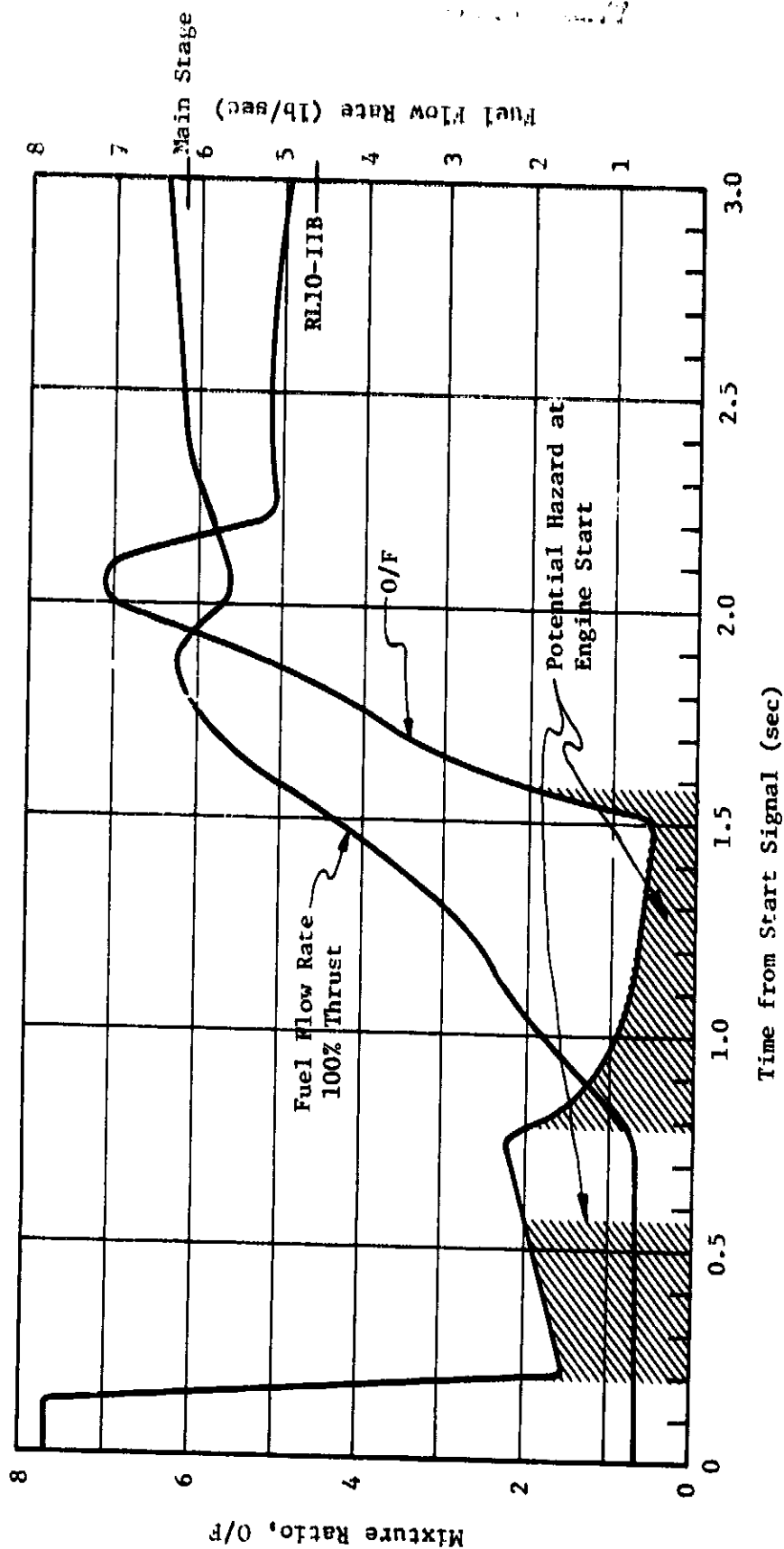


AECE-R ENGINE SECOND STAGE DIFFUSER TRANSIENT CHARACTERISTICS WITH J57 JET ENGINE EXHAUST AS DRIVER (26 lb/sec)

(Note: J57 WILL NOT BE USED AS DRIVER DURING TRANSIENTS)

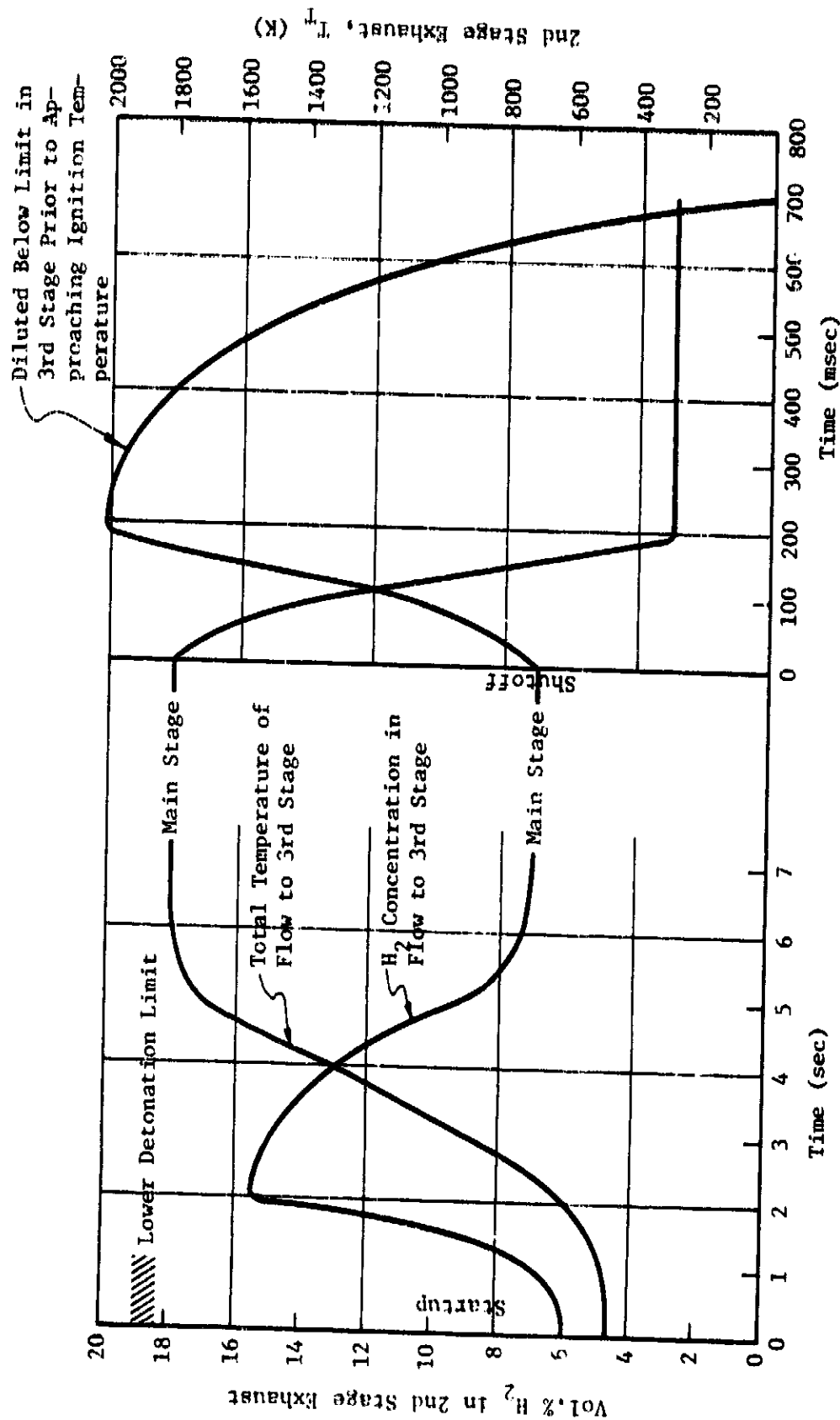


RL10A-3-3A ENGINE START TRANSIENT CHARACTERISTICS



AECE-R ENGINE 2nd STAGE DIFFUSER TRANSIENT OPERATION

(100% Thrust; Driver: GN_2 , 150 lb/sec)



LOW THRUST OPERATION

| <u>Engine Status</u> | <u>Driver</u> (Stages 1 & 2) | <u>Stage</u> | <u>RL 10-II B Engine</u> | | <u>AECE-R Engine</u> | |
|----------------------|---------------------------------|--------------|--------------------------|-----------------------------|-------------------------|-----------------------------|
| | | | <u>Exhaust</u> | | <u>Exhaust</u> | |
| | | | <u>T_T, K</u> | <u>Vol. % H₂</u> | <u>T_T, K</u> | <u>Vol. % H₂</u> |

| | | | | | | |
|--------------------|------|--------|------|------|------|------|
| Main Stage Burn | J57s | Engine | 2958 | 29.5 | 2756 | 40.6 |
| | | | 2628 | 16.9 | 2565 | 33.2 |
| | | | 1968 | 0.1 | 2310 | 1.3 |
| | | | 371 | Nil | 926 | Nil |

- H₂ is burned virtually to completion in 1st and 2nd stages.

| | | | | | | |
|--------------------|-----|--------|---------|---------|---------|---------|
| Main Stage Burn | GN2 | Engine | 2958 | 29.5 | 2756 | 40.6 |
| | | | 2461 | 15.4 | 2304 | 33.1 |
| | | | 958 | 2.8 | 955 | 8.5 |
| | | | 799-825 | 0.3-Nil | 799-878 | 0.9-Nil |

- Flow enters 3rd stage with H₂ well below detonation limit.

| | | | | | | |
|--------------------------|-----|---------------------|--------------------------|------|-----------------------------------|------|
| Start/Stop Transients | GN2 | <u>Worst Cases:</u> | <u>RL10-II B Engine:</u> | | <u>Full Fuel Flow,</u> | |
| | | | | | <u>0.466 lb H₂/sec</u> | |
| | | | <u>AECE-R Engine:</u> | | <u>Full Fuel Flow, 0.74</u> | |
| | | | | | <u>lb H₂/sec</u> | |
| | | Engine | 300 | 99.8 | 300 | 99.8 |
| | | | 300 | 56.5 | 300 | 67.3 |
| | | | 300 | 11.5 | 300 | 17.1 |

- H₂ flow is diluted with GN₂ to below detonation limit in stages 1 and 2 even with the full maximum rated flow of unburned H₂ at low thrust.

100% THRUST OPERATION

| <u>Engine Status</u> | <u>Driver</u> (Stages 1 & 2) | <u>Stage</u> | <u>RL 10-IIB Engine</u> | | <u>AECE-R Engine</u> | |
|----------------------|---------------------------------|--------------|-------------------------|---|-------------------------|---|
| | | | <u>T_T, K</u> | <u>Exhaust</u> <u>Vol. % H₂</u> | <u>T_T, K</u> | <u>Exhaust</u> <u>Vol. % H₂</u> |

Main Stage
Burn

J57s

Engine
Not Driven - 1
2
3

| | | | |
|------|------|------|------|
| 2958 | 29.5 | 2958 | 29.5 |
| 2958 | 29.5 | 2958 | 29.5 |
| 2872 | 16.3 | 2869 | 15.8 |
| 1545 | Nil | 1519 | Nil |

- H₂ is burned as rapidly as it mixes in 2nd and 3rd stages.

Main Stage
Burn

GN2

Engine
Not Driven - 1
2
3

| | | | |
|------|------|------|------|
| 2958 | 29.5 | 2958 | 29.5 |
| 2958 | 29.5 | 2958 | 29.5 |
| 1855 | 7.4 | 1806 | 7.1 |
| 1324 | Nil | 1300 | Nil |

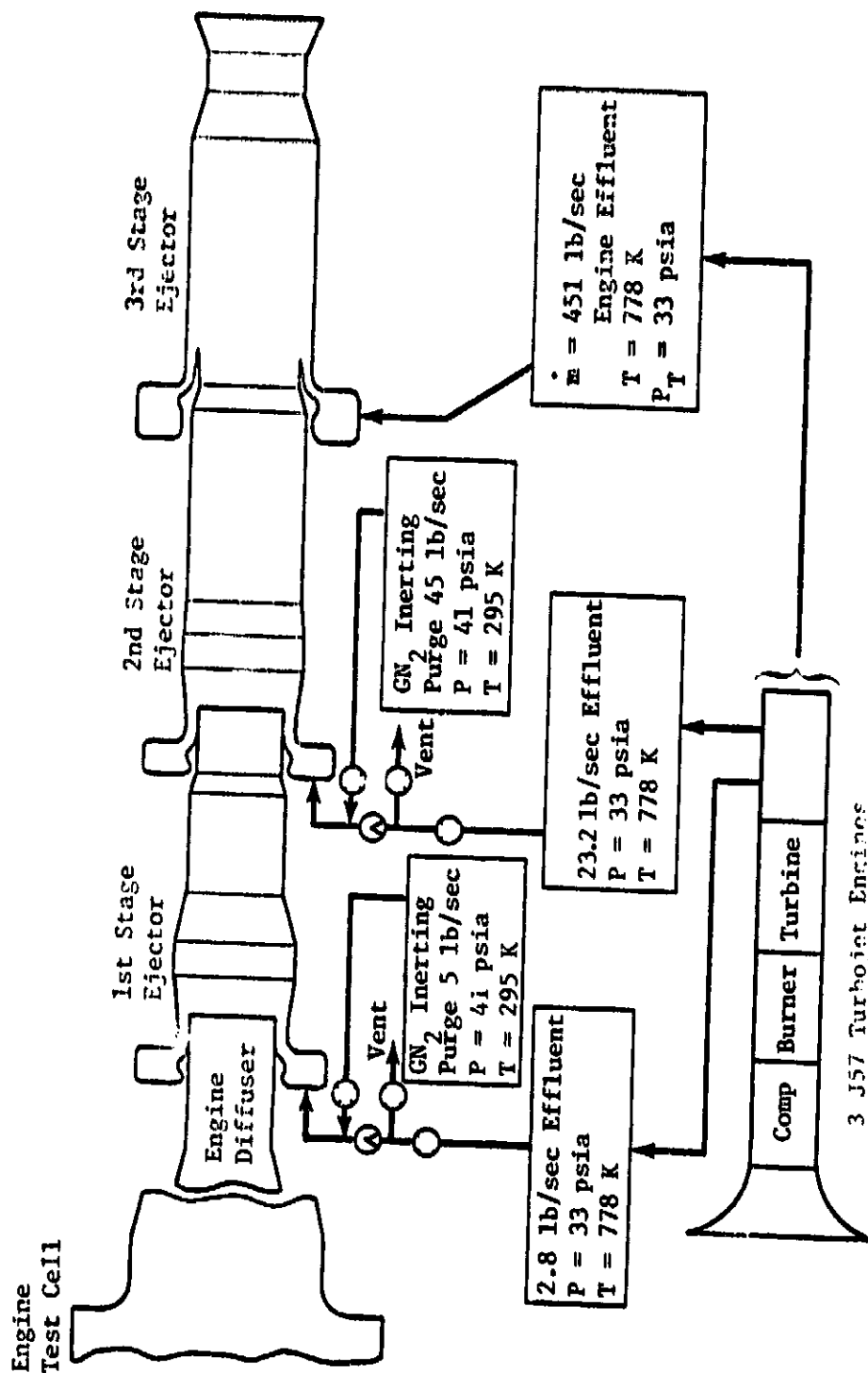
- H₂ flow is diluted with GN2 to well below detonation limit in 2nd stage and burns as rapidly as it mixes in 3rd stage.

Stop/Start
Transients

GN2

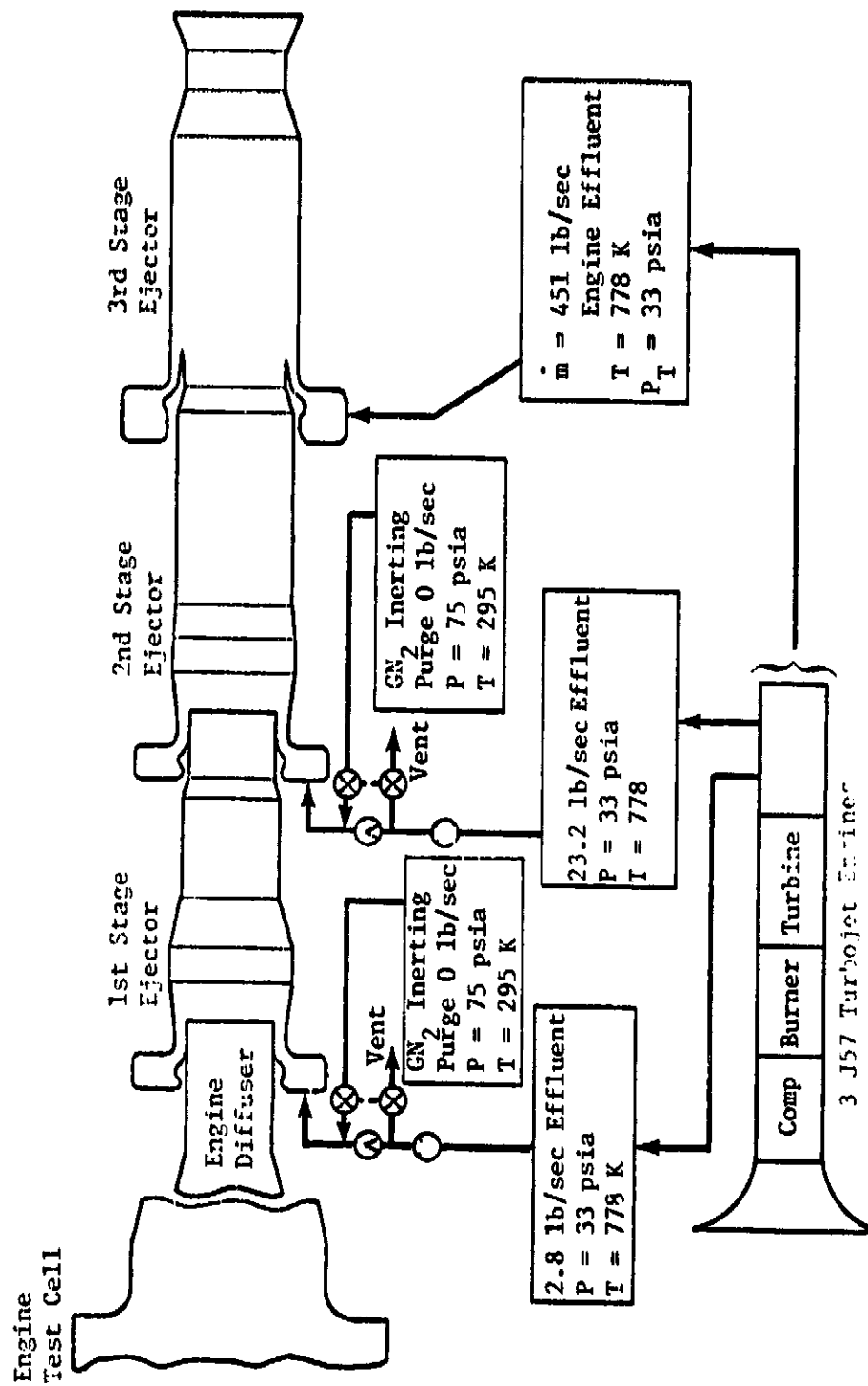
- H₂ in flow is diluted and cooled with GN2 to below detonation limit in 2nd stage.

RL10-IIB AND AECE-R STARTUP AND SHUTDOWN OPERATION FULL SCALE 10% THRUST JET ENGINE DRIVEN EJECTOR/DIFFUSER SYSTEM



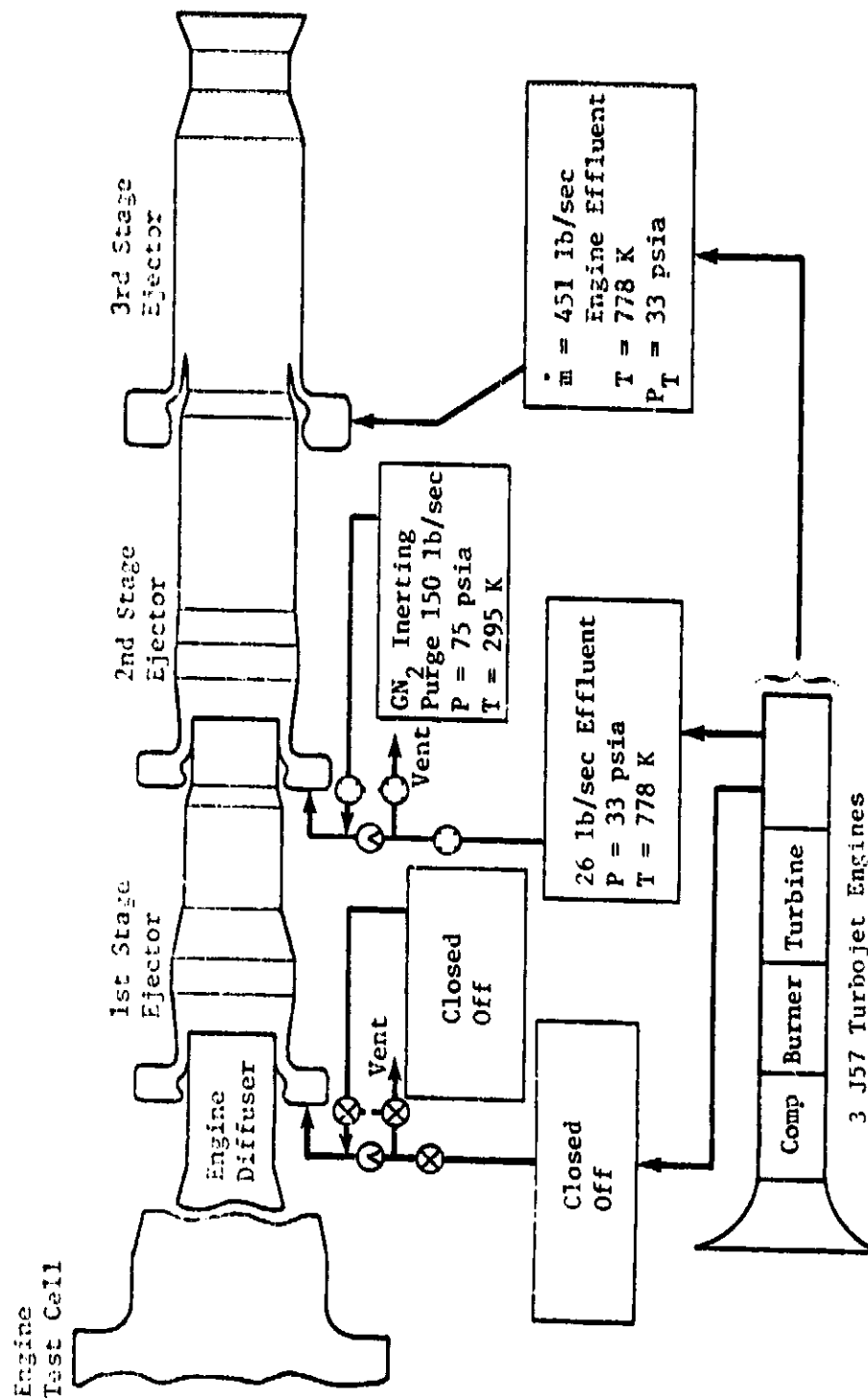
RL10-11B OR AECE-R ENGINE STEADY STATE OPERATION

FULL SCALE 10% THRUST JET ENGINE DRIVEN EJECTOR/DIFFUSER SYSTEM

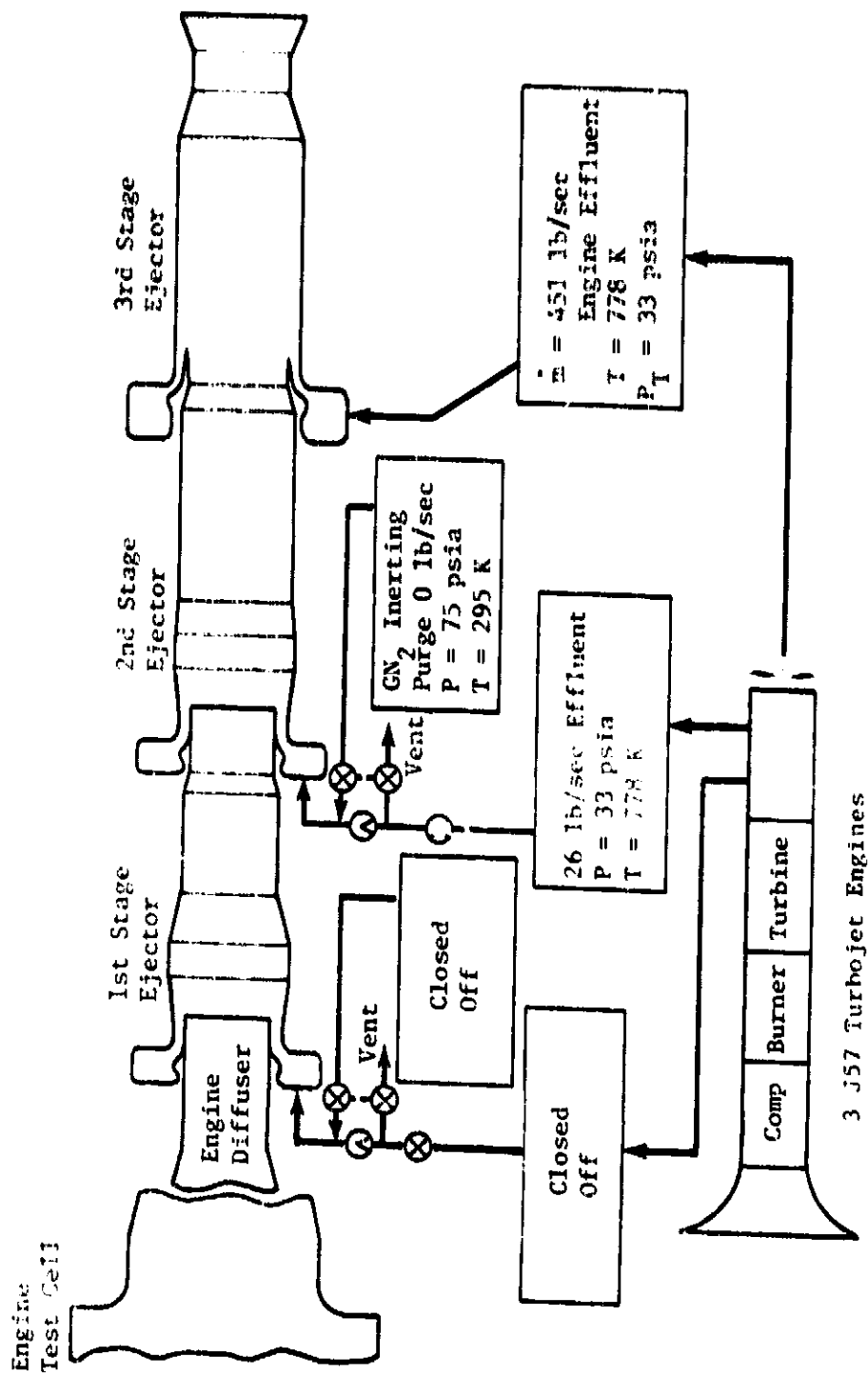


RL10-IIB OR AECE-R ENGINE STARTUP AND SHUTDOWN OPERATION

FULL SCALE 100% THRUST JET ENGINE DRIVEN EJECTOR/DIFFUSER SYSTEM



RL10-11B OR AECE-R ENGINE STEADY STATE OPERATION



Appendix B
ORIGINAL STRESS NOTES
SUBSCALE FACILITY PRELIMINARY DESIGN

by
D.M. Tilley
Structures & Materials Group

FOREWORD

This strength analysis was performed as a preliminary check on the safety and feasibility of the overall design approach as of April 1984. The overall dimensions of the basic structures were used with conservative load assumptions. No attention was given at this time to detailed parts. This limited analysis does not constitute an endorsement of the design for fabrication.

CONTENTS

| | Page |
|--|------|
| FOREWORD | B-11 |
| SUBSCALE FACILITY MARGIN SUMMARY | B-1 |
| MATERIAL PROPERTIES | B-3 |
| SUBSCALE FACILITY OPERATING CONDITIONS | B-4 |
| STRUCTURAL ANALYSIS | B-8 |
| SUBSCALE FACILITY SUPPORT STRUCTURE | B-48 |

| | | | | | |
|------------------|--------------|---|-------------|-------|-------|
| Prepared by: TMT | Date: 4/2/71 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 1.0 | Temp: | Part: |
| Checked by: | Date: | Title: SUBSCALE, EXHAUST/DIFFUSERS | Model: | | |
| Approved by: | Date: | AVIATION COMMAND - ALIN | Report No.: | | |

| Drawn | DESCRIPTIONS | BUCKLING | ULT | YIELD |
|---------|---|----------|---------|--------|
| R82704 | ALTITUDE SIMULATION CELL | + 11.16 | + 24.3 | + 21.6 |
| R82706 | ALTITUDE CELL & PLATE | --- | + 9.35 | + 8.24 |
| R82701 | INLET PLATE | | + 1.1 | + 8.75 |
| R82702 | H ₂ CYLINDER - | --- | + 7.5 | + .56 |
| R82708 | ALTITUDE CELL & PLATE | --- | + 9.35 | + 8.24 |
| R82709 | NOZZLE DISCHARGE TUBE | + 1.86 | + 96.2 | + 85.8 |
| R82710 | EXHAUSTION SECTION - NOZ. SIM. | + 78.6 | + 36.96 | + 32.9 |
| R82714 | EJECTOR KING - FIRST STAGE | + 49.3 | + 4.03 | + 3.12 |
| R82716 | EXHAUSTION SECTION - 1 ST STAGE | + 24.3 | + 6.33 | + 5.0 |
| R82715 | ADJUSTABLE TUBE ASSY | + 22.4 | + 27.7 | + 27.7 |
| R82717 | FIRST STAGE CONTRACTION SECT. | + 10.4 | + 27.9 | + 27.9 |
| R82718 | 1 ST TO 2 ND STRAIGHT SECTION | + 5.6 | + 30.0 | + 27.9 |
| R82723A | EJECTOR KING - 2 ND STAGE | + 25.16 | + 4.3 | + .17 |
| R82723 | EXHAUSTION SECTION - 2 ND STAGE | + 20.0 | + 10.1 | + 8.1 |
| R82724 | ADJUSTABLE TUBE ASSY | + 11.72 | + 52.2 | + 18.0 |
| R82726 | 2 ND TO 3 RD STAGE STRAIGHT | + .95 | + 40.1 | + 7.33 |
| R82728 | 2 ND STAGE EJECTOR KING | + 1.52 | + 10.32 | + 8.27 |

| | | | | | |
|-------------------------|-------------------|---|------------------|-------|------------|
| Prepared by: EXT | Date: 4/74 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 1.1 | Temp. | Perm. |
| Checked by: | Date: | Title | Model | | |
| Approved by: | Date: | NOZZLE EJECTOR / DIFFUSER ALLEN SCHWARTZ - MIN | | | Report No. |

| NO. | DESCRIPTION | WEIGHT | WLT. | YLD. |
|-------------------------------------|--------------------------------------|--------|-------|-------|
| R82727 | R82712 3 RD STAGE EJECTOR | +11.77 | +7.18 | +2.59 |
| R82729 | CORRUGATE SECTION - THIRD STAGE | +17.98 | +9.03 | +2.67 |
| R82731 | STRAIGHT SECTION - THIRD STAGE | +1.97 | +9.3 | +2.67 |
| R82730 | EXIT TAPER SECTION | +8.3 | +9.29 | +2.67 |
| R82706 | NOZZLE BODY | | +75 | +56 |
| R827037 | STRUCTURAL SUPPORT | | +74 | +84 |
| | SLIDING BEARING PIPE | | +37 | +50 |
| | DIAGONAL TORSIONER | | +31 | |
| | TOP OF FRAME BEAM | | +1.08 | +1.78 |
| | SIDE OF FRAME BEAM | | +2.11 | +3.17 |
| | FASTENERS TO TAIL | | +4.44 | |
| ORIGINAL PAGE IS OF POOR QUALITY | | | | |
| | B-2 | | | |

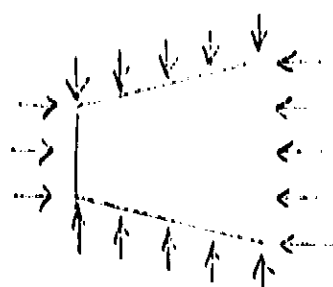
MATERIAL PROPERTIES 304 L STAINLESS STEEL

| 304 L ST. ST. | E | F _{TU} | F _{CY} |
|----------------|------------------------|-----------------|-----------------|
| At RT | 28 x 10 ⁶ | 70 ksi | 25 ksi |
| 312 F (772 R) | 27 x 10 ⁶ | 59 ksi | 22 ksi |
| 440 F (900 R) | 25.5 x 10 ⁶ | 55 ksi | 18 ksi |
| 778 F (1238 R) | 23 x 10 ⁶ | 51.5 ksi | 13.5 ksi |

| | | | |
|----------------------------|--------------------|---|---|
| Prepared by: <u>CAIT</u> | Date <u>12/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page <u>1</u> Temp. <u> </u> Print <u> </u> |
| Checked by: <u> </u> | Date <u> </u> | Title <u>SUBSCALE EJECTOR/DIFFUSER</u> | Model <u> </u> |
| Approved by: <u> </u> | Date <u> </u> | <u>AXIAL LOADS</u> | Report No. <u> </u> |

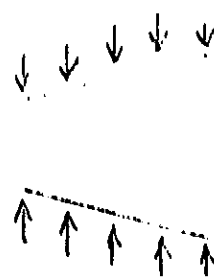
NOTE:

AXIAL LOADS IN THE SUBSCALE EJECTOR/DIFFUSER TUBING ARE ACCOUNTED FOR THROUGH THE CALCULATIONS OF HYDROSTATIC TENSILE AND ALLOWABLE PRESSURES. THEREFORE, UNLESS A NEGATIVE PRESSURE IS USED IN ANALYSIS, A PIPE SECTION FOR TENSILE, AXIAL LOADS ARE ASSUMED AS THOUGH THE ENDS WERE FIXED.



HYDROSTATIC PRESSURE

STRESS
OF TUBING



LATERAL PRESSURE

SINCE AXIAL STRESS DUE TO HYDROSTATIC PRESSURE IS HALF THAT OF HOOP STRESS, AXIAL STRESSES ARE NOT CALCULATED.

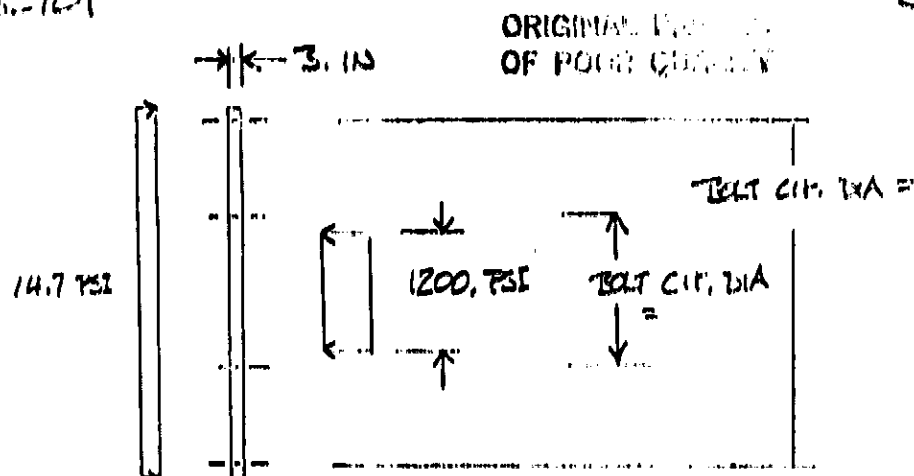
— AN EXCEPTION TO THIS IS FOR SECTIONS BETWEEN THE REACTION STATIONS AND THE EJECTORS, THE FLOW ENERGY ENTERING THE SYSTEM AT THE EJECTORS IS REACTED AXIALLY THRU THE TUBING TO THE REACTION STATIONS. THIS AXIAL LOAD WOULD NOT BE ACCOUNTED FOR UNDER THE HYDROSTATIC ASSUMPTION ABOVE.

ALL LOCKHEED EQUATIONS ARE FROM
NASA STRUCTURES MANUAL, SECTION C.3.0.

| | | | |
|-----------------------|---------------|---|-------------|
| Prepared by: T. M. T. | Date: 11/2/44 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 1.21 |
| Checked by: | Date: | Title: SUBSALZ INLET/DIFFUSER | Model: |
| Approved by: | Date: | INLET PLATE | Report No.: |

TR 701

304 L.S.S.



SINCE THE 1200 PSI LOAD OVERWHELMED THE 14.7 PSI LOAD ALL CONSIDERATIONS WILL BE MADE TO THE LARGER LOAD.

— FOR THE HIGH PRESSURE DIAMETER OF ~ 2 IN. THE 900 LB FLANGE STANDARD GIVES A BLIND FLANGE THICKNESS OF $Q = 2 \frac{1}{2}$ IN (ZEROK PAGE 110-111) OR ASA B16.5 MATERIAL → ASTM A105 GRADE II

— MATERIAL ASTM A105 GRADE II $F_y = 36$ KSI (ZEROK P-153)

— F_T RATIO = $\frac{\text{ASTM A105 GRADE II}}{304 L} = \frac{36}{25} = 1.44$

— THE 900 LB STANDARD HAS A WORKING PRESSURE OF 2160 PSI AT RT. (ZEROK PAGE 151)

— 2.5 IN. 304 L HAS A WORKING PRESSURE OF $2160/1.44 = 1500$ PSI.

— THE 3. IN THICKNESS SHALL HAVE A WORKING PRESSURE OF AT LEAST $(3/2.5) 1500 = 1800$.

M.S. = $1800/1200 - 1 = 0.5$ + 5 YLD

100% FACTOR OF SAFETY OF 2.

| | | | |
|------------------|-----------|---|------------|
| Prepared by: DLT | Date 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page 1.5 |
| Checked by: | Date | Title | Model |
| Approved by: | Date | SMALL INJECTOR/DIFFUSER INLET PLATE | Report No. |

REZ701

304 L S.S.

ADJUSTING MARGIN CALCULATIONS TO REFLECT 4 & 1.6
OLD ULT. & YLD :

$$M.S. = 2(1800) / 1.6(1200) - 1. = +1.875 YLD$$

RELATIONSHIPS 304 L ULT/YLD STRENGTHS :

$$M.S. = \left(\frac{70}{25}\right) 2(1800) / 4(1200) - 1. = +1.1 ULT$$

ORIGINAL FILED
OF POOR QUALITY

ORIGINAL. INSTEAD
OF POOR QUALITY

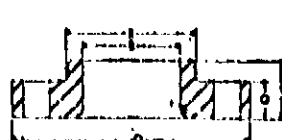
| Part Number | Part Name | Material | Size | Length | Weight | Notes | Quantity | Price | Total | | |
|----------------------|-----------|----------|----------|--------|---|---------|-----------|----------|-------|--------|--------|
| 18-8 Cr Ni Type 304 | A 182 | F 304 | Flange | .00 | 2.0 Max | 1.0 Max | 10.0/20.0 | 8.0/11.0 | 1 | 70,000 | 70,000 |
| | A 312 | TP 304 | Pipe | .00 | 2.0 Max | .75 Max | 10.0/20.0 | 8.0/11.0 | 1 | 70,000 | 70,000 |
| | A 403 | WP 304 | Fittings | | Covers Manufactured Fittings For Chem-Stream Other Specifications Apply | | | | | | |
| | A 403 | WP 304L | Fittings | .025 | 2.0 Max | .75 Max | 10.0/20.0 | 8.0/13.0 | 1 | 70,000 | 70,000 |
| 18-8 Cr Ni Type 304L | A 312 | TP 304L | Pipe | .00 | 2.0 Max | .75 Max | 10.0/20.0 | 8.0/13.0 | 1 | 70,000 | 70,000 |
| | A 182 | F 304L | Flange | .00 | 2.0 Max | 1.0 Max | 10.0/20.0 | 8.0/13.0 | 1 | 70,000 | 70,000 |



Pipe Line Type — Part No. 734†



Pipe Line Type - Part No. 754f



For sizes 1/2" through 2 1/2" use 1500 lb. flanges.

EQWY : MSC 302 A

| | | | | |
|------------------|------------|--|-------------|-------|
| Prepared by: TMT | Date: 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 19 | Form: |
| Checked by: | Date: | Title: SURFAC2 EJECTOR DIFFUSER | Model: | |
| Approved by: | Date: | H ₂ CYLINDER - NOZ. SIMULATOR | Report No.: | |

TR82702 304 L S. S.

LEAD - 1200 PSIA / 12T ?

0.875 IN THK.

6.875

120

ORIGINAL PAGE 19
OF POOR QUALITY

HOOP STRESS

$$\sigma = PD / 2t = (1200) 6.875 / 2 (0.875) = 4714. \text{ PSI}$$

$$M.S. = \frac{70K}{4} (4714) - 1. = +2.71 \text{ YLT}$$

$$M.S. = \frac{25K}{1.6} (4714) - 1. = +2.31 \text{ YLD}$$

FLANGE THICKNESSES OF 2.5 IN ARE USED WITH THE SAME THICKNESS AS INLET PLATE THICKNESS (TR82701).

$$M.S. = \frac{1500}{1200} - 1 = +.25$$

WITH A YIELD FACTOR OF 2 IN THE NUMERATOR,

$$M.S. = \frac{2(1500)}{1.6(1200)} - 1. = +1.56 \text{ YLD}$$

WITH A YIELD FACTOR OF 1.6 & RATIONING THE YLT:

$$M.S. = \frac{70K}{25K(2)} 1500 / 4 (1200) - 1. = +1.75 \text{ YLT}$$

| | | | | | |
|------------------|------------|---|------------|-------|-------|
| Prepared by: DMT | Date: 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 1.12 | Temp. | Perm. |
| Checked by: | Date: | Title: CENTRAL NOZZLE/DIFFUSER | Model: | | |
| Approved by: | Date: | NOZZLE BODY | Report No. | | |

TR82706

304 L S.S.

— THE NOZZLE BODY SUPPORT CAN BE CONSIDERED A 'BLIND FLANGE' AND USING THE RATIONALE ON PAGE 1 (FOR THE END PLATE - TR82701) THE 2.5 IN. THICKNESS HAS A WORKING PRESSURE OF 1500 PSI.

— THIS WORKING PRESSURE HAS A YIELD FACTOR OF SAFETY OF AT LEAST 2. THEREFORE

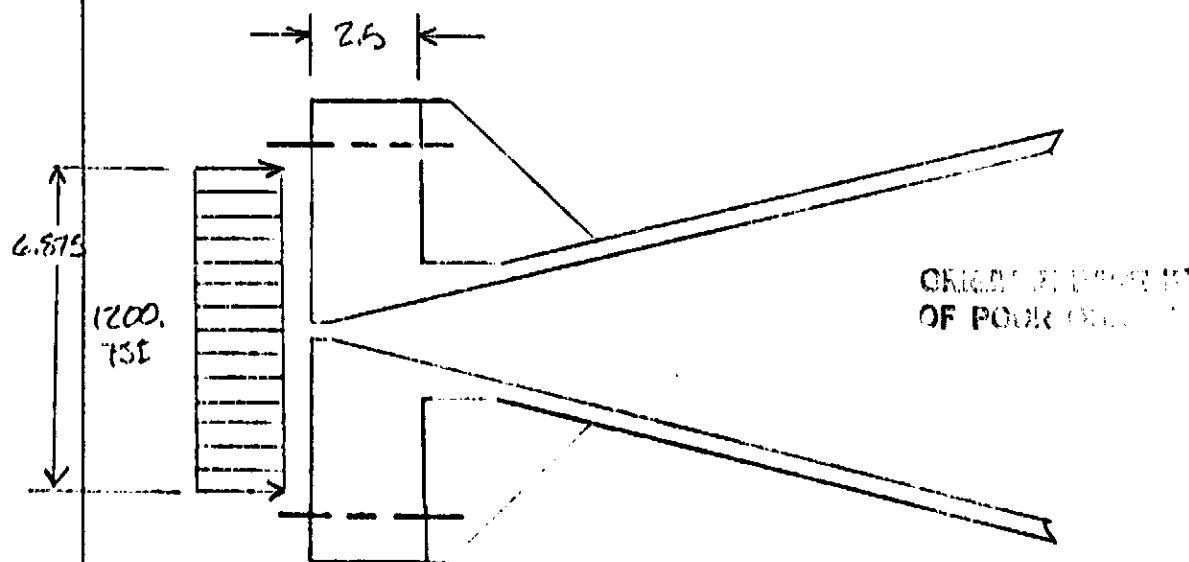
$$M.S. = 2(1500) / 1.6(1200) - 1. = \underline{\underline{+1.56 \text{ YLD}}}$$

RATIONING FOR THE ULT MARK-115:

$$M.S. = \left(\frac{70}{25}\right) 2(1500) / 4(1200) - 1. = \underline{\underline{+1.75 \text{ ULT}}}$$

CONSERVATIVE

GUSSETS ARE CONSERVATIVELY IGNORED



| | | | |
|--------------|------|-------------|------------|
| Checked by: | Date | Title | Model |
| Approved by: | Date | NOZZLE BODY | Report No. |

TR82706

304L S. S.

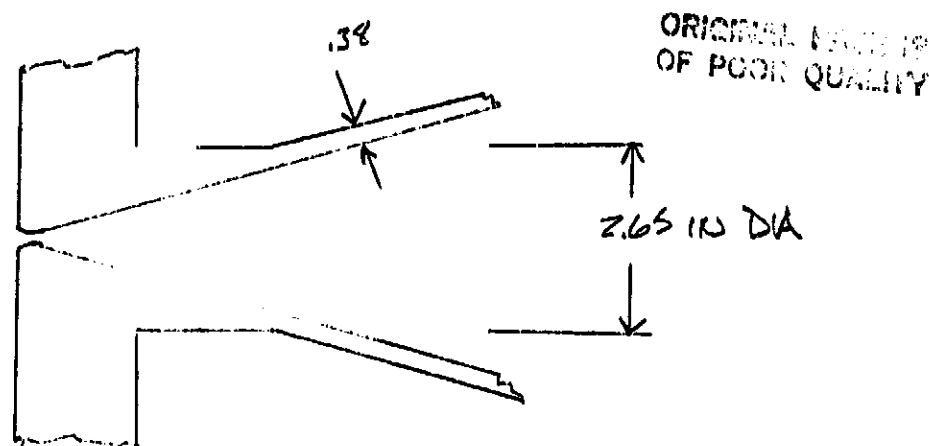
THROAT OF NOZZLE -

ASSUME 1200 PSI AT ID = 2.65 & T = .38 & R.T.
IGNORE GUSSETS

$$\sigma = PD/2t = 1200(2.65)/2(.38) = 4184 \text{ PSI}$$

$$M.S. = 70/4(4.184) - 1.0 = \underline{\underline{+3.18}}$$

$$M.S. = 25/1.6(4.184) - 1.0 = \underline{\underline{+2.73}}$$



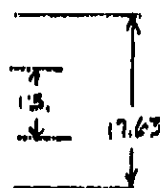
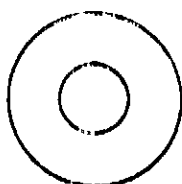
- CONSERVATIVE LOAD - SINCE 1200 PSIA DECREASES FROM ORIFICE TO NOZZLE S END.

| | | | | | |
|-------------------------|-------------------|---|----------------------|-----------------|----------------|
| Prepared by: <u>ENT</u> | Date: <u>4/24</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>22</u> | Temp. <u> </u> | Hum. <u> </u> |
| Checked by: <u> </u> | Date: <u> </u> | Title: <u>EXTERNAL FUEL/DEFUSER</u> | Model: <u> </u> | | |
| Approved by: <u> </u> | Date: <u> </u> | <u>ARTICLE CELL & TANK</u> | Report No. <u> </u> | | |

DWG 782708

304L SS

GUIDE STEPS -



THK = .5IN

LOAD = 14.7 PSI NOMINAL PRESSURE
AT TGT.

PLUS CENTER LOAD = $14.7 \pi 6.5^2 = 1951$ LB.

ROARK ST² ED P336 CASE 1.F $w = 1951 / 2\pi 6.5 = 47.77$ lb/in

$M_{RB} = w a L_0 / C_s = 47.8 (8.81) .028 / .228 = 51.74$ lbs

$$L_0 = \frac{13}{4(17.63)} \left[\left(\frac{13}{17.63} \right)^2 - 1 + 2 \ln \left(\frac{17.63}{13} \right) \right] = .028$$

$$C_s = \frac{1}{2} \left[1 - \left(\frac{13}{17.63} \right)^2 \right] = .228$$

$$\text{SO } \sigma_B = 6M / t^2 = 6(51.74) / .25 = 1380.75 \text{ PSI}$$

CASE 2F $M = q a^2 L_{14} / C_s = 14.7 (8.81^2) .0026 / .228 = 13.02$ lbs

$$L_{14} = \frac{1}{16} \left[1 - \left(\frac{13}{17.63} \right)^4 - 4 \left(\frac{13}{17.63} \right)^2 \ln \frac{17.63}{13} \right] = .0026$$

$$\text{SO } \sigma_B = 6M / t^2 = 6(13.02) / .25 = 312.6 \text{ PSI}$$

$$\sigma_T = 1380. + 312.6 = 1692. \text{ PSI}$$

$$M.S. = 70. / 4 (1.69) - 1. =$$

$$+ 9.35 \text{ ULT}$$

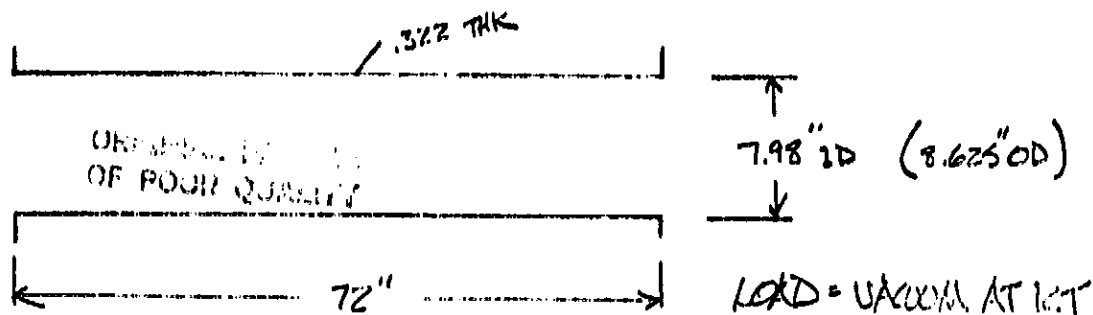
$$M.S. = 25. / 1.6 (1.69) - 1. =$$

$$+ 8.24 \text{ ylb}$$

| | | | |
|------------------|------------|---|-------------|
| Prepared by: LMT | Date: 4/24 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 3 |
| Checked by: | Date: | Title: SCRAMJET ENGINE / DIFFUSER | Model: |
| Approved by: | Date: | NOZZLE DISCHARGE TUBE | Report No.: |

DWG 1282709

304L SS



REF. NASA STRUCTURES MANUAL, SECT C3, P.13

$$D = E t^3 / 12 (1 - \nu^2) = 28 \times 10^6 (.322^3) / 12 (.9215) = 84537.$$

$$Z = L^2 (1 - \nu^2) Y^2 / RT = 72^2 \sqrt{.9215} / 4.3 (.322) = 3514.$$

$$T_{LR} = K_P \pi^2 D / R L^2 = 4.5 \pi^2 84537 / 4.3 (72)^2 = 168.4 \text{ psi}$$

HYDROSTATIC PRESSURE WHERE $\lambda = .56$ $\lambda Z = 2017.6$
 $K_P = 4.5$

$$M.S. = 168.4 / 4 (14.7) = \underline{\underline{+11.86 \text{ BUCKLING}}}$$

HOOP STRESS

$$\sigma = PD / 2t = 14.7 (7.98) / 2 (.322) = 180.7 \text{ PSI}$$

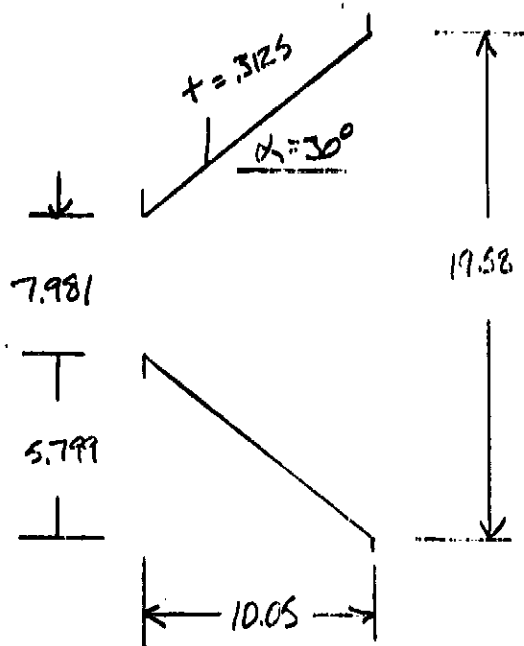
$$M.S. = 70. / 4 (.18) - 1. = \underline{\underline{+96.2 \text{ YIELD}}}$$

$$M.S. = 25 / 1.6 (.18) - 1. = \underline{\underline{+85.8 \text{ YIELD}}}$$

| | | | | | |
|-------------------------|-------------------|---|----------------|--------|--------|
| Prepared by: <u>DIT</u> | Date: <u>4/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>1</u> | Temp.: | Perm.: |
| Checked by: | Date: | Title: <u>SUBSAL INJECTOR/DIFFUSOR</u> | Model: | | |
| Approved by: | Date: | EXPANSION SECTION - NOZ. SIMULATION | Report No.: | | |

R82710

ESC/4 L S. S.



LOAD UNIFORM AT IZT

HYDROSTATIC PRESSURE --
CONSERVATIVE.

CLASH
OF PARTS

REF. NASA STRUCTURES MANUAL, SECT. C3.0, P 67.

$$\text{Buckling} - P_{cr} = .12 E \times \left(\frac{L}{r} \right) \left(\frac{\bar{P}}{t} \right)^{5/2} \text{ where } \bar{P} = (9.79 + 4.) / 2 \cos 30^\circ = 7.95$$

$$= .92 \times 10^6 \times 75 / \left(\frac{10.05}{7.95} \right) \left(\frac{7.95}{.3125} \right)^{5/2} = 4681 \text{ PSI}$$

$$M.S. = 4681 / 4(14.7) - 1. =$$

+ 78.6 BUCKLING

HOOP STRESS - CONSERVATIVE

$$\sigma = PD / 2t = 147(19.6) / 2(.3125) = 461. \text{ PSI}$$

$$M.S. = 70 / 4(.461) - 1. =$$

+ 36.96 ULT

$$M.S. = 25 / 1.6(.461) - 1. =$$

+ 32.9 YLD

| | | | | | |
|------------------|-----------|---|------------|-------|------|
| Prepared by: DMT | Date 6/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page | Temp. | Per. |
| Checked by: | Date | Title | Model | | |
| Approved by: | Date | EJECTOR/DEFUSER EJECTOR TANK - FIRST STAGE | Report No. | | |

TR52714

AXIAL LOAD ON THE 10.35 IN. CYLINDER DUE TO
EJECTOR FLOW:

AXIAL LOAD DUE TO EJECTOR PRESSURE OF 6.34 PSIA:

$$P = 6.34 \pi (20.72^2 - 19.584^2) / 4 = 46.44 \text{ PSI}$$

$$\text{AXIAL STRESS} = \frac{P}{A} = \frac{46.44(2)}{.375(2)\pi 19.584} = 2.01 \text{ PSI}$$

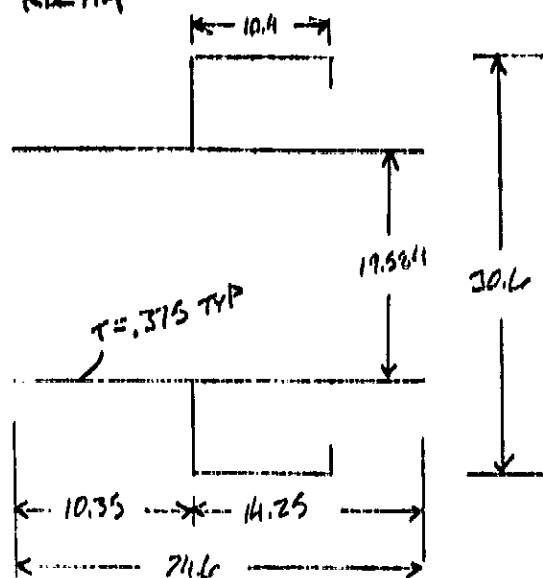
NEGLECTIBLE

ORIGINAL OF POOR QUALITY

| | | | |
|------------------|------------|---|-------------|
| Prepared by: DMT | Date: 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 5 |
| Checked by: | Date: | Title: SUBSIST. EJECTOR/DIFFUSER | Model: |
| Approved by: | Date: | EJECTOR TRING - FIRST STAGE | Report No.: |

DWG RB2714

304 L S. S.



LOAD - VACUUM AT 9000 R
(CONSERVATIVE)

$$E = 26 \times 10^6 \text{ PSI} - 440 F$$

$$F_{cy} = 18 \text{ KSI} - 440 F$$

INNER CYLINDER - BUCKLING REF NASA STRUCTURES MANUAL, C.3, P.13

$$D = E t^3 / 12 (1 - \nu^2) = 26 \times 10^6 (.375)^3 / 12 (.9215) = 123991$$

$$Z = L^2 (1 - \nu^2)^{1/2} / 12 T = 14.25^2 \sqrt{.9215} / 9.8 (.375) = 53.04$$

$$P_{cr} = \frac{K_p \pi^2 D}{R L^2} = 6 \pi^2 123991 / 9.8 (14.25^2) = 3689 \text{ PSI}$$

1/1000 STAT/L

$$\sigma = .56 \quad \sigma Z = .56 (53) = 29.7 \quad K_p = 6$$

$$M.S. = 3689 / 4 (14.7) - 1. = \underline{\underline{+61.7}}$$

HOOP STRESS

$$\sigma = PD / 2T = (14.7) (19.584) / 2 (.375) = 383.8 \text{ PSI}$$

$$M.S. = 55 / 4 (.384) - 1. = \underline{\underline{+34.8 \text{ ULT}}}$$

$$M.S. = 18 / 1.6 (.384) - 1. = \underline{\underline{+28.3 \text{ YLD}}}$$

| | | | |
|--------------------------|------------------|---|---------------|
| Prepared by: <u>DAIT</u> | Date <u>4/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page <u>6</u> |
| Checked by: | Date | Title <u>SURVIVAL EJECTOR/DIFFUSER</u> | Model |
| Approved by: | Date | <u>EJECTOR RINGS - FIRST STAGE</u> | Report No. |

DWG - R82714

304 L 9.5

OUTER CYLINDER

ORIGINAL POWER
OF POOR QUALITY

BUCKLING:

$$D = 26(10^6) \cdot 375^3 / 12(1.9215) = 123991$$

$$Z = 10.4^2 \sqrt{1.9215} / 15.3(375) = 18.09$$

$$T_{CR} = \frac{4}{\pi^2} \frac{123991}{15.3(10.4^2)} = 2957.9 \text{ PSI}$$

HYDROSTATIC

$$KZ = 1.56(18.1) = 10.85 \quad K = 4$$

$$M.S. = 2958 / 4(14.7) - 1 =$$

+49.3 BUCKLING

LOOP STRESS

$$\sigma = PD / ZT = (14.7) 30.6 / 2(375) = 600 \text{ PSI}$$

$$M.S. = 55. / 4(600) - 1 =$$

+21.9 ULT

$$M.S. = 18. / 1.6(600) - 1 =$$

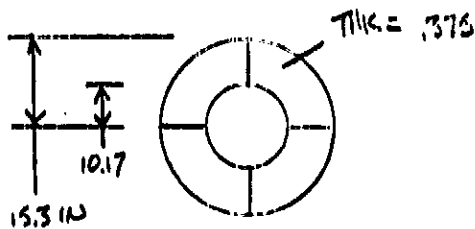
+17.7 YLD

| | | | |
|-------------------------|--------------------|---|----------------|
| Prepared by: <u>WLT</u> | Date: <u>11/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>7</u> |
| Checked by: | Date: | Title: <u>SPECIAL 2 SECTOR DIFFUSER</u> | Model: |
| Approved by: | Date: | <u>EXHAUST TRAYS - FIRST STAGE</u> | Report No.: |

DWG TR27114

SDH 1. S.S.

- TRING — OUTER CYLINDER END
- ASSUME ALL ACTUATOR LOADS REACTED BY INNER GUSSET.
 - VERY CONSERVATIVELY IGNORE INNER GUSSETS FOR THE FOLLOWING THERMAL LOADING.



LOAD — VACUUM AT 440°F
 $F = 26 \times 10^6$ KSI
 $F_{tu} = 55$ KSI
 $F_{ty} = 18$ KSI

ORIGINAL OF FOUR

REF-ROARK 5TH ED, P 340, CASE 2F.

$$M_{RB} = q_0^2 L_{14} / C_s = 14.7 (15.3)^2 .00518 / .279 = 63.96$$

$$C_s = .5 \left[1 - \left(\frac{10.17}{15.3} \right)^2 \right] = .279$$

$$L_{14} = \frac{1}{16} \left[1 - \left(\frac{10.17}{15.3} \right)^4 - 4 \left(\frac{10.17}{15.3} \right)^2 \ln \left(\frac{15.3}{10.17} \right) \right] = .00518$$

$$\sigma = 6M / t^2 = 6(64.) / .375^2 = 2729.7 \text{ PSI}$$

$$M.S. = 55 / 4(2.73) - 1. = \left| \begin{array}{l} +4.03 \text{ ULT} \\ \text{VERY CONSERVATIVE} \end{array} \right|$$

$$M.S. = 18. / 1.6(2.73) - 1. = \left| \begin{array}{l} +3.12 \text{ YLD} \\ \text{VERY CONSERVATIVE} \end{array} \right|$$

| | | | | | |
|-------------------------|-------------------|--|----------------|------------|-------|
| Prepared by: <u>DAT</u> | Date: <u>4/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>9</u> | Temp. | Form. |
| Checked by: | Date: | Title: <u>SUPERCAL EXPANDER/DIFFUSER</u> | Model: | | |
| Approved by: | Date: | EXPANSION SECTION - 1ST STAGE | | Report No. | |

DWG R82716

JOHL S.S.

CONJ. LOAD = -14.7 PSI @ RT

ORIGINAL PAGE 12
OF POOR QUALITY

REF NASA STRUCTURES MANUAL, C3.0, P67

$$P_{ct} = \frac{.92 E \delta}{\left(\frac{L}{r}\right)\left(\frac{r}{t}\right)^{3/2}} = \frac{.92 (28 \times 10^6) .75}{\left(\frac{24.16}{13.22}\right)\left(\frac{13.22}{.375}\right)^{3/2}} = 1432.65 \text{ PSI}$$

$$\bar{r} = (15.5 + 10.365) / 2 \cos 12 = 13.22$$

$$M.S. = 1432 / 14.7 (4) - 1. =$$

HYDROSTATIC
BUCKLING
+24.31

HOOP STRESS

$$\sigma = P D / 2t = 14.7 (31.) / 2 (.375) = 607.6 \text{ PSI}$$

$$M.S. = 10. / 1.6 (607.6) - 1. =$$

$$M.S. = 25. / 1.6 (607.6) - 1. =$$

1.717
ULT.
+24.7
YLD.

| | | | | | |
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| Prepared by: <u>LMT</u> | Date: <u>4/8/44</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>10</u> | Temp: <u></u> | Point: <u></u> |
| Checked by: <u></u> | Date: <u></u> | Title: <u>SUPPLINE SELECTOR/DIFFUSER</u> | Model: <u></u> | | |
| Approved by: <u></u> | Date: <u></u> | <u>EXPANSION SECTION - 1ST STAGE</u> | Report No. <u></u> | | |

DWG R82716

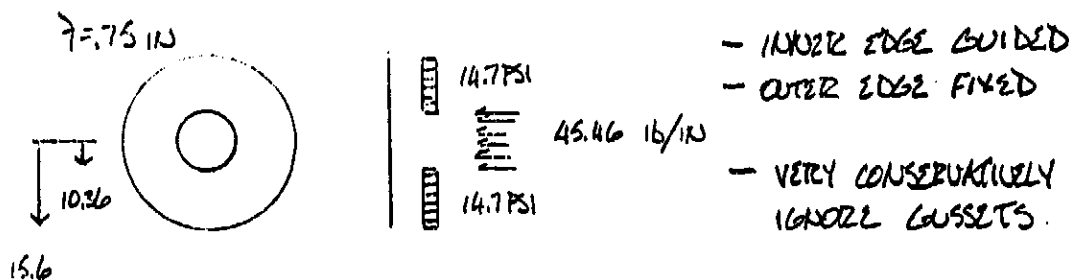
304 L S.S.

RING — $a = 15.6$ $b = 10.36$ $\gamma = .75$

LOAD = -14.7 PSIG (CONSERVATIVE) & AXIALLY LOADED

INNER EDGE OF 294/TT 20.73 = 45.46 lb/in = w
440°F

REF TRACK - 5TH 2D, P 336, CASE 1.F



$$M = w a L_0 / C_s = 45.46 (15.6) .043 / .279 = 109.11$$

$$L_0 = \frac{10.36}{4 (15.6)} \left[\left(\frac{10.36}{15.6} \right)^2 - 1 + 2 \ln \frac{15.6}{10.36} \right] = .043$$

$$C_s = .5 \left[1 - \left(\frac{10.36}{15.6} \right)^2 \right] = .279$$

CASE 2F

$$M = q a^2 L_{14} / C_s = 14.7 (15.6)^2 .0052 / .279 = 66.675$$

$$L_{14} = \frac{1}{16} \left[1 - \left(\frac{10.36}{15.6} \right)^4 - 4 \left(\frac{10.36}{15.6} \right)^2 \ln \frac{15.6}{10.36} \right] = .0052$$

$$\sigma = 6(109.11 + 66.7) / .75^2 = 1875 \text{ PSI}$$

$$M.S. = 18000 / 1.6 (1875) - 1. = \underline{+5. \text{ YLD}}$$

$$M.S. = 55000 / 4. (1875) - 1. = \underline{+6.33 \text{ YLT}}$$

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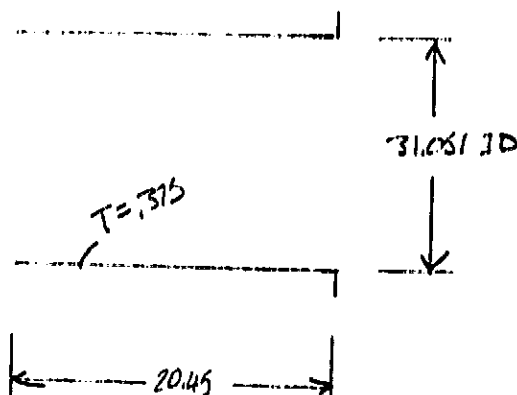
B-26

VERY CONSERVATIVE

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| Prepared by: <u>WLT</u> | Date <u>4/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page <u>11</u> |
| Checked by: | Date | Title | Model |
| Approved by: | Date | <u>SUBSONIC EJECTOR/DIFFUSER</u> | Report No. |
| | | <u>ADJUSTABLE FLUX ASSY</u> | |

WUXOTR82715

304L S.S.



LOAD = -14.7 PSK AT ET
CONSERVATIVE

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REF. - NASA STRUCTURES MANUAL, C3, P 13

$$D = E t^3 / 12 (1 - \nu^2) = 28 \times 10^6 (.375)^3 / 12 (.9215) = .133528$$

$$Z = L^2 (1 - \nu^2)^{1/2} / \pi T = 20.45^2 (.9215) / 15.52 (.375) = 68.97$$

$$P_{cr} = K_p \pi^2 D / 12 L^2 = 6.5 \pi^2 .133528 / 15.52 (20.45)^2 = 1319.7 \text{ psi}$$

WHERE $\phi = .56$ & $\phi Z = .386$ & $K_p = 6.5$

$$M.S. = 1320 / 4 (14.7) - 1. =$$

HYDROSTATIC
BUCKLING
+22.4

HOOP STRESS

$$\sigma = PD / 2t = 14.7 (31.05) / 2 (.375) = 608.58 \text{ PSI}$$

$$M.S. = 28000 / 1.6 (609.) - 1. =$$

+27.7 YLD

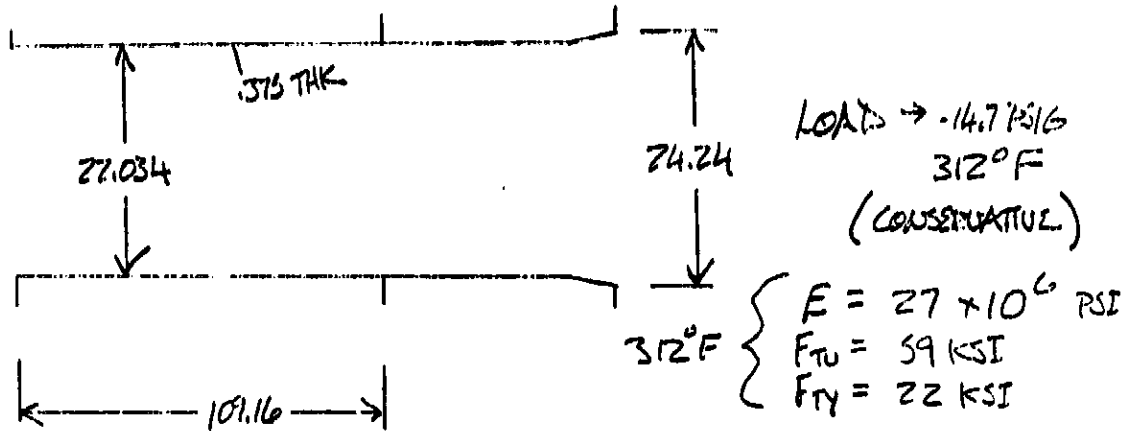
$$M.S. = 70000 / 4 (609.) - 1. =$$

+27.7 ULT

| | | | | | |
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| Prepared by: DAT | Date: 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 13 | Temp. | Perm. |
| Checked by: | Date: | Title: SUBSICAL VECTOR/DIFFUSER | Model: | | |
| Approved by: | Date: | 1ST TO 2ND STAGE STRAIGHT SECTION | Report No. | | |

R82718

ORIGINAL PAGE 304L - S.S.
OF POOR QUALITY



REF: NASA STRUCTURES MANUAL, C3.0, P. 13

$$D = 27 \times 10^6 (.375^3) / 12 (.9215) = 128746.$$

$$Z = 109.16^2 \sqrt{.9215} / 11 (.375) = 2773$$

$$P_{cr} = 40 \pi^2 128746 / 11 (109.16)^2 = 387.76 \text{ PSI}$$

$$Z\delta = .56 (2773) = 1552. \quad K_P = 40$$

$$M.S. = 387.8 / 4 (14.7) - 1. = +5.59$$

BUCKLING
HYPER-EL

Hoop Stress - BASED ON MAX DIA

$$\sigma = P D / 2t = 14.7 (24.24) / 2 (.375) = 475. \text{ PSI}$$

$$M.S. = 22 / 1.6 (.475) - 1. = +27.9$$

YLD

$$M.S. = 59 / 4 (.475) - 1. = +30.05$$

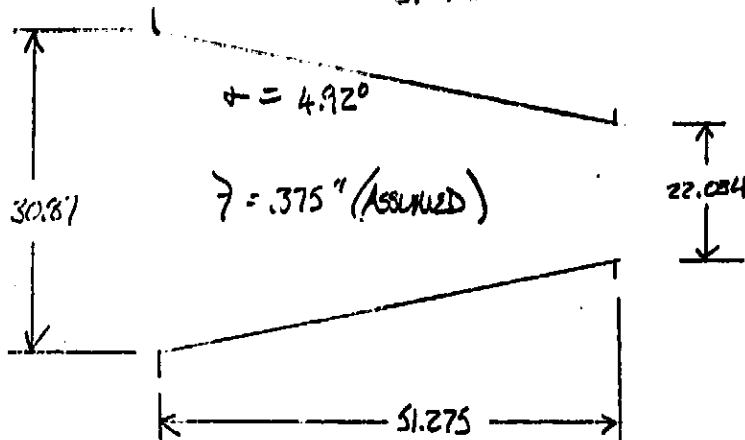
ULT

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| Prepared by: TMT | Date: 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 12 |
| Checked by: | Date: | Title: SUBSCALE VECTOR/DIFFUSER | Model: |
| Approved by: | Date: | FIRST STAGE CONTRACTION SECTION | Report No.: |

R82717

304L S.S.

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LOAD $\rightarrow -14.77516$
TCT (CONSERVATIVE.)

$$\bar{r} = \frac{30.87 + 22.034}{4 \cos 4.92^\circ} = 13.27$$

REF. - NASA STRUCTURES MANUAL, C3.0, P67.

$$P_{cr} = \frac{.92 E t}{\left(\frac{L}{\bar{r}}\right) \left(\frac{\bar{r}}{t}\right)^{\frac{5}{2}}} = \frac{.92 (28 \times 10^6) .75}{\left(\frac{51.275}{13.27}\right) \left(\frac{13.27}{.375}\right)^{\frac{5}{2}}} = 671. \text{ PSI}$$

$$M.S. = 671. / 4. (14.7) - 1. =$$

+10.4

HYDROSTATIC
BUCKLING

HOOP STRESS

$$\sigma = PD/2t = 14.7 (30.87) / 2 (.375) = 605. \text{ PSI}$$

$$M.S. = 28000. / 1.6 (605.) - 1. =$$

+27.9
YIELD

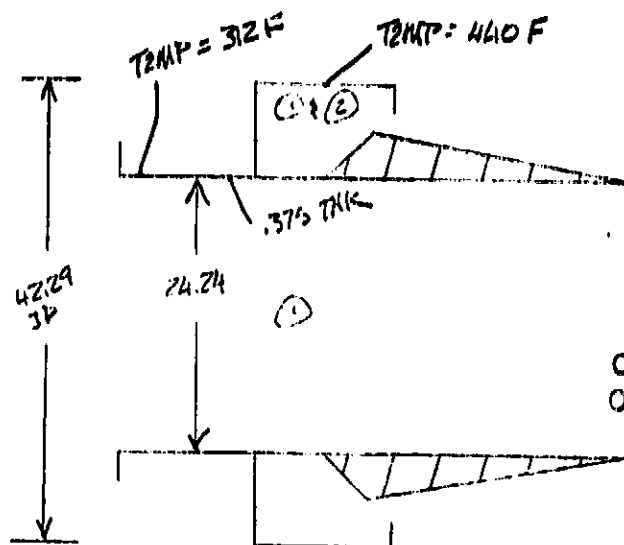
$$M.S. = 70000. / 4. (605.) - 1. =$$

+27.9
ULT

| | | | | | |
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| Prepared by: DMT | Date: 11/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 14 | Temp.: | Hum.: |
| Checked by: | Date: | Title: | Model: | | |
| Approved by: | Date: | SUBSCALE INJECTOR / DIFFUSER | | | Report No.: |
| | | EJECTOR TANK - 2ND STAGE | | | |

DWG - R82723A

304 L - S.S.



LOAD: ① -14.7 PSIG AT 312 F
(CONSERVATIVE)

② 33 PSIA = 18.3 PSIG
AT 440 F

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OF POOR QUALITY

← 12. * 12.5 →

INNER CYLINDER

BUCKLING REF NASA STRUCTURES MANUAL, C3.0, P. 13

$$D = 27 \times 10^6 (.375^3) / 12 (.9215) = 128746.$$

$$Z = 12^2 \sqrt{.9215} / 12.12 (.375) = 30.41$$

$$P_{cr} = 5 \pi^2 128746. / 12.12^2 (12^2) = 4010.9$$

$$Z \cdot P = .56 (30.41) = 17. \quad K_p = 5.$$

$$M.S. = 4011 / 4 (14.7) - 1. =$$

$$\begin{array}{r} + 67.2 \\ \hline \text{BUCKLING} \\ \text{HYDROSTATIC} \end{array}$$

HOOP STRESS - SAME AS PREVIOUS SECTION:

$$+ 27.9 \text{ KSI}$$

$$+ 30.05 \text{ KSI}$$

| | | | |
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| Prepared by: DML | Date: 6/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 14.1 |
| Checked by: | Date: | Title: ROCKET EJECTOR / LATTICE | Model: |
| Approved by: | Date: | EJECTOR TRAIL - SECOND STAGE | Report No.: |

TC82723A

AXIAL LOAD IN 12.0 IN CYLINDRICAL SECTION DUE TO EJECTOR FLOW:

$$P = (33 - 14.7) \pi (32^2 - 24.2^2) / 4 = 6300 \text{ LB}$$

$$\sigma = P/A = 6300 / \pi 12.1^2 = 13.7 \text{ PSI}$$

THIS WOULD CORRESPOND TO A HYDROSTATIC PRESSURE OF:

$$\sigma = \frac{PD}{4t} = 13.7 = P \cdot 24.2 / 4 (0.375)$$

$$\uparrow P = 0.85 \text{ PSI}$$

SINCE THE HYDROSTATIC BUCKLING OF THIS CYLINDER IS

4010.9* PSI \rightarrow GOOD BY INSPECTION

* PREVIOUS PAGE.

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| Prepared by: <u>LNT</u> | Date: <u>4/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>15</u> | Temp. | Print. |
| Checked by: | Date: | Title: <u>SUBSCALE EJECTOR / DIFFUSER</u> | Model: | | |
| Approved by: | Date: | <u>EJECTOR TANK - 2ND STAGE</u> | Report No. | | |

DWG - T82723A

304L - S.S.

OUTER CYLINDER BUCKLING - REF MAX STRUCTURES MAXIAL
(WALL TEMP = 1440 F)
 $D = 27 \times 10^6 (.375^3) / 12 (.9215) = 128746$

$$Z = 12.5^2 \sqrt{.9215} / 21.145 (.375) = 18.91$$

$$P_{cr} = \frac{4}{\pi^2} 128746 / 21.145 (12.5^2) = 1538.4 \text{ PSI}$$

$$KZ = .56 (18.91) = 10.6 \quad K_P = 4$$

$$M.S. = 1538.4 / 4 (14.7) - 1. = \underline{\underline{+25.16}}$$

BUCKLING
HYDROSTATIC

HOOP STRESS (LOAD 2) (USING MAX POS. PRESSURE, 33-14.7 = 18.3 PSIG)

$$\sigma = PD/2t = 18.3 (42.29) / 2 (.375) = 1031.87 \text{ PSI}$$

$$M.S. = 55 \text{ KSI} / 4. (1032.) - 1. =$$

$$\underline{\underline{+12.3}}$$

ULT

$$M.S. = 13 \text{ KSI} / 1.6 (1032.) - 1. =$$

$$\underline{\underline{+9.9 \text{ YIELD}}}$$

ORIGINAL PAGE 15
OF POOR QUALITY

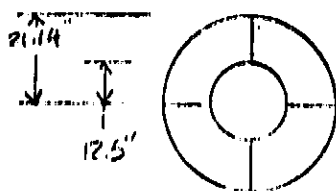
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| Prepared by: <u>DAT</u> | Date: <u>11/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>16</u> |
| Checked by: | Date: | Title: <u>INTERNAL EXHAUSTOR / DIFFUSER</u> | Model: |
| Approved by: | Date: | <u>EXHAUSTOR RING - SECOND STAGE</u> | Report No.: |

DWG TC82723A

SCALE - S.S.

RING

ORIGINAL FIGURE
OF FOUR QUARTERS



18.3756

18.3756

LOAD - MAX ΔP IS 18.3 PSIG

AT 440.1 F

$F_{TU} = 55$ KSI

$F_{TY} = 18$ KSI

- THE LOADS FROM THE ACTUATORS ARE ASSUMED TO BE REACTED THROUGH THE INNER GUSSETS.
- VERY CONSERVATIVELY IGNORE THE FOUR INNER GUSSETS WHEN CONSIDERING THE PRESSURE ON THE RING.

REF: ROARK STTH EDITION, P 340, CASE 2F. $r_0 = b$

$$M_{RB} = q a^2 L_{14} / C_s = 18.3 (21.14^2) .008932 / .325 = 224.63$$

$$C_s = .5 \left[1 - \left(\frac{12.5}{21.14} \right)^2 \right] = .325$$

$$L_{14} = \frac{1}{16} \left[1 - \left(\frac{12.5}{21.14} \right)^4 - 4 \left(\frac{12.5}{21.14} \right)^2 \ln \frac{21.14}{12.5} \right] = .008932$$

$$q = 6M / r^2 = 6(224.6) / .375^2 = 9584.4 \text{ PSI}$$

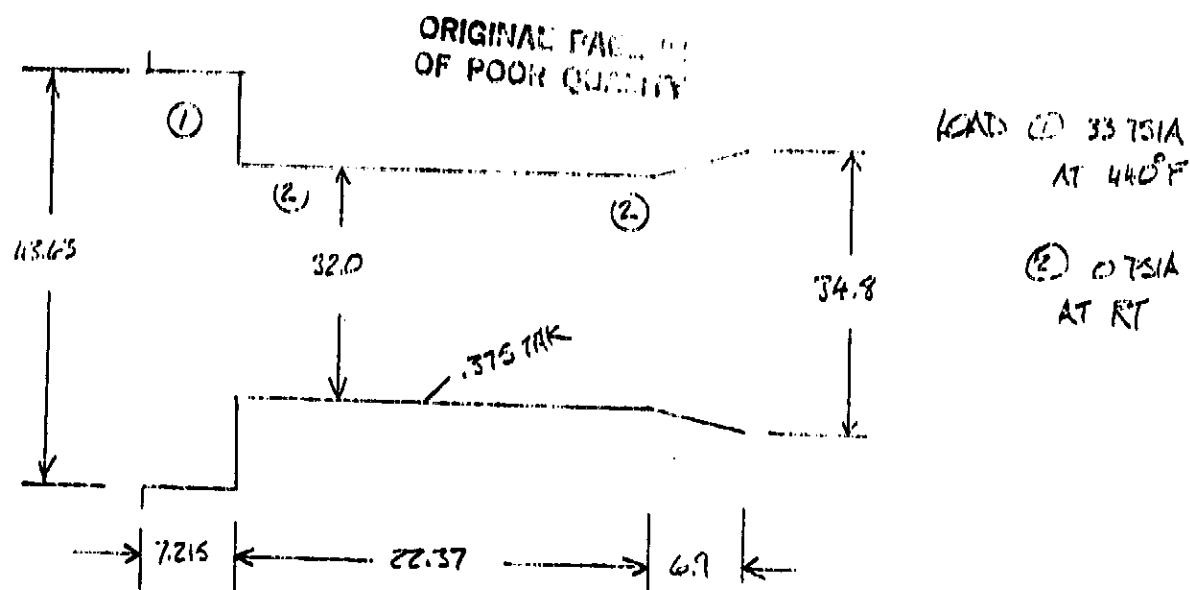
$$M.S. = 55 / 4 (9.584) - 1 = \underline{+ .43 \text{ ULT CONSERVATIVE}}$$

$$M.S. = 18 / 1.6 (9.584) - 1 = \underline{+ .17 \text{ YIELD CONSERVATIVE}}$$

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| Prepared by: <u>DUT</u> | Date: <u>4/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>17</u> |
| Checked by: | Date: | Title: <u>SEVEN. 2ND OR DIFFUSER</u> | Model: |
| Approved by: | Date: | <u>2ND STATION SECTION - SECOND STAGE</u> | Report No.: |

TUXE R82723

304L 3.5.



BUCKLING OF LARGE DIA CYL - IN VACUUM AT 440°F - CONSERVATIVE
TE2F. - NASA STRUCTURES MANUAL, C3.0, P.13.

$$D = 25.5 \times 10^6 (.375^3) / 12 (.9215) = 128746.$$

$$Z = 7.2^2 \sqrt{9.125} / 21.81 (.375) = 6.08$$

$$P_{CR} = 2.6 \pi^2 128746 / 21.81 (7.215^2) = 2911.155$$

$$Z \times = .56 (6.08) = 3.4 \quad K_P = 2.6$$

$$M.S. = 2911. / 4. (14.7) - 1. = +48.5 \text{ BUCKLING}$$

HOOP STRESS - US2 33-14.7 = 18.3 TSIG AT 440°F

$$\sigma = TD / Zt = 18.3 (43.63) / Z (.375) = 1064.75I$$

$$M.S. = 55. / 4 (1064) - 1. = +11.92 \text{ ULT}$$

$$M.S. = 18. / 1.6 (1064) - 1. = +9.67 \text{ YLD}$$

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| Prepared by: DALT | Date: 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 18 | Temp: 18 | Form: |
| Checked by: | Date: | Title: SUBSCALE INJECTOR/DIFFUSER | Model: | | |
| Approved by: | Date: | EXPANSION SECTION - SECOND STAGE | Report No.: | | |

DWG 282723

304 1- S.S.

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BEKING OF LONG CYLINDER - REF. NASA STRUCTURES MANUAL

$L = 22.37 \text{ in}, R = 16. \text{ in.}, \text{ THICKNESS} = .375$
LOAD - VACUUM AT DET.

$$D = 28 \times 10^6 (.375^3) / 12. (.9215) = 133528.$$

$$Z = 22.37^2 \sqrt{.9215} / 16. (.375) = 79.67$$

$$P_r = 7.5 \pi^2 133528 / 16. (22.37^2) = 1234.$$

$$Zr = .66 (79.67) = 44.6, K_P = 7.5$$

$$M.S. = 1234. / 4 (14.7) - 1. =$$

$$+ 19.98$$

HYDROSTATIC
BEKING

HOOP STRESS

$$\sigma = PD / 2t = 14.7 (32.) / 2 (.375) = 627. \text{ PSI}$$

$$M.S. = 70 / 4 (.627) - 1. =$$

$$+ 26.9 \text{ ULT}$$

$$M.S. = 28 / 1.6 (.627) - 1. =$$

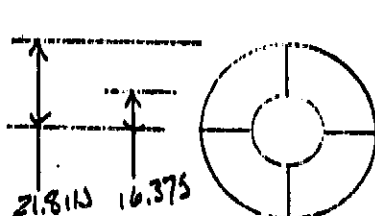
$$+ 26.9 \text{ YLD}$$

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| Prepared by: DMT | Date: 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 19 | Form: |
| Checked by: | Date: | Title: SPIRALS INJECTOR/DIFFUSER | Model: | |
| Approved by: | Date: | EXPANSION SECTION - SECOND ST. | Report No. | |

R82723

JOAL S.S.

CYLINDER THING — ASSUME TIEBACKS TIEACT ACTUATOR LOAD
 — VERY CONSERVATIVELY IGNORE TIEBACKS IN THING
 PRESSURE ANALYSIS BELOW



THK = .66

LOAD = 18.3 PSIG AT 440°F

REF: ROARK STTH ED, PAGE 7.340, CASE 2F. $r_o = b$

$$M_{KB} = q a^2 L_{14} / C_s = 18.3 (21.8^2) .00223 / .217 = 89.76$$

$$C_s = .5 \left[1 - (16.4/21.8)^2 \right] = .217$$

$$L_{14} = \frac{1}{16} \left[1 - \left(\frac{16.375}{21.8} \right)^4 - 4 \left(\frac{16.375}{21.8} \right)^2 \ln \frac{21.8}{16.375} \right] = .00223$$

$$\sigma = 6M / t^2 = 6(89.76) / .66^2 = 1236 \text{ PSI}$$

$$M.S. = 55 / 4 (1.236) - 1 = \underline{+10.12 \text{ ULT}}$$

$$M.S. = 18 / 1.6 (1.236) - 1 = \underline{+8.1 \text{ YLD}}$$

CONSERVATIVE

ORIGINAL DESIGN
 OF POOR QUALITY

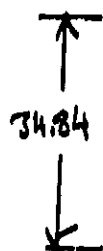
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| Prepared by: DMT | Date 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page 22 |
| Checked by: | Date | Title SPECIAL SELECTOR/DIFFUSION | Model |
| Approved by: | Date | ADJUSTABLE PLUG ASSY. | Report No. |

R82724

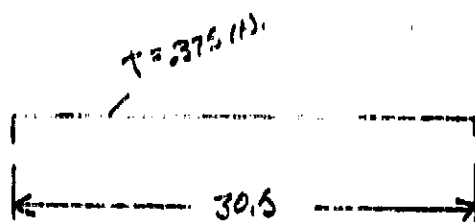
3041 S. 5.

ORIGINAL FIGURE
OF POOR QUALITY

LOAD ① VACUUM AT RT



② 43151A BOOST
(43-14.7 = 28.3 PSIG)
AT RT



[CONSERVATIVELY MAXIMIZE
SLIGHT CIRCULAR ENDS.]

BUCKLING - REF NASA STRUCTURES MANUAL, 23.0, P 13

$$D = E t^3 / 12 (1 - \nu^2) = 28 \times 10^6 (375)^3 / 12 (0.9215) = 133528.8$$

$$Z = L^2 (1 - \nu^2)^{1/2} / \pi T = 30.5^2 (0.9215)^{1/2} / 17.42 (375) = 136.7$$

$$P_{cr} = K_p \pi^2 D / \pi L^2 = 9.2 \pi^2 133528.8 / 17.42 (30.5^2) = 748.9 \text{ psi}$$

$$\phi = .56 \quad Z\phi = .56 (136.7) = 76.55$$

$$K_p = 9.2$$

$$M.S. = 748.2 / 4 (14.7) - 1. =$$

$$\begin{array}{r} + 11.72 \\ \hline \text{BUCKLING} \\ \text{HYDROSTATIC} \end{array}$$

HOOP STRESS - FOR ABOVE LOAD CASE

$$\sigma = P D / 2t = 14.7 (34.84) / 2 (375) = 682.8 \text{ PSI}$$

$$M.S. = 28 / 1.6 (682) - 1. = \begin{array}{r} + 24.62 \\ \hline \text{YIELD} \end{array}$$

HOOP STRESS - FOR BURST PRESSURE OF 28.3 PSIG

$$\sigma = P D / 2t = 28.3 (34.84) / 2 (375) = 1314.6 \text{ PSI}$$

$$M.S. = 70 / (1.314) - 1. = \begin{array}{r} + 52.2 \\ \hline \text{U.T.} \end{array}$$

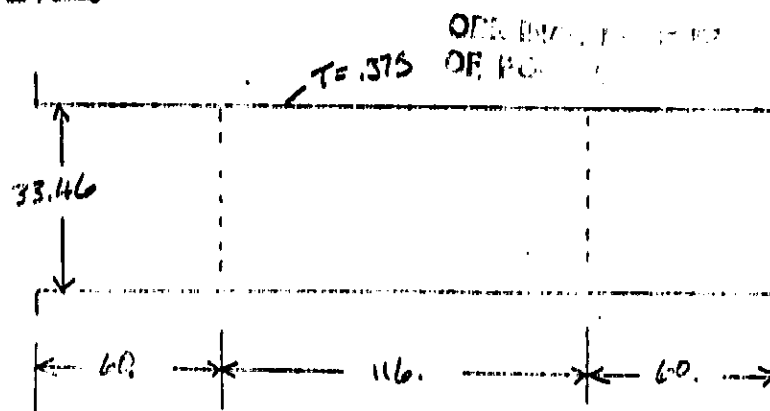
$$M.S. = 25 / (1.314) - 1. = \begin{array}{r} + 18.9 \\ \hline \text{YIELD} \end{array}$$

B-37

| | | | | | |
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| Prepared by: <u>DLT</u> | Date: <u>4/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>21</u> | Temp. <u> </u> | Form. <u> </u> |
| Checked by: <u> </u> | Date: <u> </u> | Title: <u>SUBSONIC EXTERIOR DIFFUSION</u> | Model: <u> </u> | | |
| Approved by: <u> </u> | Date: <u> </u> | SECOND TO THIRD STAGE STRAIGHT SECT. | | Report No. <u> </u> | |

TS827260

304 L S. S.



LOAD — ① VACUUM
AT 778°F

② 28.3 PSIG
AT 778°F

BUCKLING — REF NASA STRUCTURES MANUAL, C3.0, P13

$$D = 2.3 \times 10^6 (.375^3) / 12 (.9215) = 109684$$

$$Z = 116^2 \sqrt{.9215} / 16.73 (.375) = 2058.9$$

$$P_{cr} = 35 \pi^2 109684 / 16.73 (140.3)^2 = 115 \text{ PSI}$$

$$K = .56 \quad KZ = .56 (2058.9) = 1152$$

$$M.S. = 115 / (4 (14.7) - 1) =$$

$$K_P = 35$$

$$+ .95 \text{ HYDROSTATIC BUCKLING}$$

HOOP STRESS — FOR ABOVE LOAD CASE

$$\sigma = PD / 2t = 14.7 (33.46) / 2 (.375) = 655 \text{ PSI}$$

$$M.S. = 13.5 / 1.6 (.655) - 1 = + 11.88 \text{ YLD}$$

HOOP STRESS — FOR BURST PRESSURE

$$\sigma = PD / 2t = 28.3 (33.46) / 2 (.375) = 1262 \text{ PSI}$$

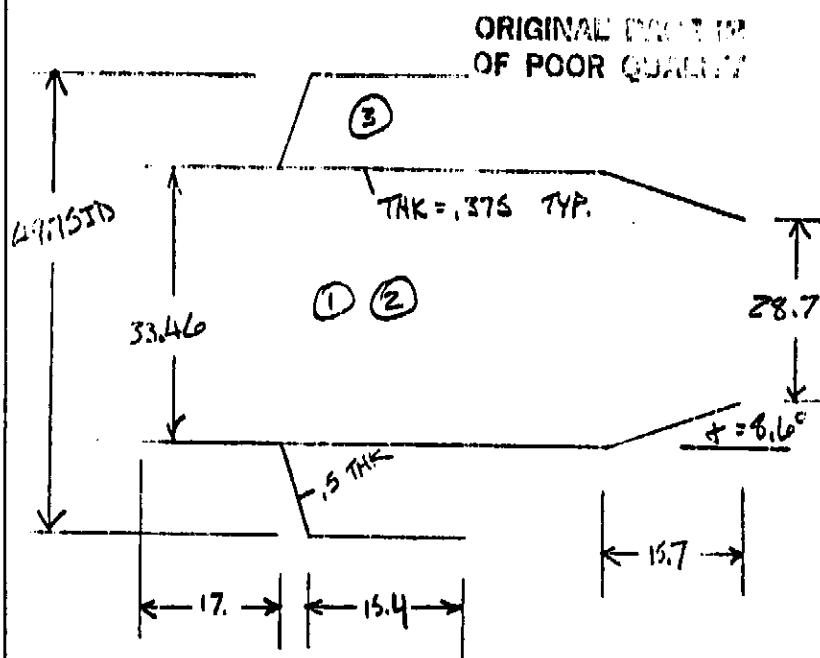
$$M.S. = 51.5 / (1.262) - 1 = + 40.1 \text{ ULT}$$

$$M.S. = 13.5 / (1.262) - 1 = + 7.33 \text{ YLD}$$

| | | | | | |
|------------------|-----------|---|---------|-------|------------|
| Prepared by: DMT | Date 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page 22 | Temp. | Perm. |
| Checked by: | Date | Title | Model | | |
| Approved by: | Date | SUBCINZ EXHAUST/DIFFUSER TANK STR. EXHAUST RINGS | | | Report No. |

TR82728

304 L.S.S.



LOAD --

① - 14.7 PSIG @ RT F

② - 28.3 PSIG @ RT
EXHAUST PERMANENT

③ - 18.3 PSIG @ 440°F

INNER CYLINDER - REF. NASA STRUCTURES MANUAL, C3.0, P. 73

BUCKLING (LOAD ①) $D = 28 \times 10^6 (375^3) / 12 (9215) = 133528.$

$Z = 17^2 \sqrt{9215} / 16.73 (375) = 44.21, ZK = .56 (44.21) = 24.76$

$P_{cr} = 5.2 \pi^2 133528. / 16.73 (17^2) = 1417. \text{ PSI}$

M.S. = $1417. / 4 (14.7) - 1. =$

+23. BUCKLING

HOOP STRESS - LOAD ②

$\sigma = PD / 2t = 28.3 (33.46) / 2 (.375) = 1262.5$

M.S. = $70. / (1262.5) - 1. =$

154.4 ALT

M.S. = $25. / (1262.5) - 1. =$

118.8 YLD

LOAD CASE ③ $\tau = 14.7 (33.46) / 2 (.375) = 645.8 \text{ PSI}$

M.S. = $28. / 1.6 (.65) - 1. =$

11-39

+25.7 YLD

| | | | | | |
|-------------------------|-------------------|---|----------------|-------|-------|
| Prepared by: <u>DMT</u> | Date: <u>6/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page <u>27</u> | Temp. | Prim. |
| Checked by: | Date: | Title: <u>SURVAL2 EJECTOR/DIFFUSER</u> | Model: | | |
| Approved by: | Date: | <u>THIRD STAGE EJECTOR TRAIL</u> | Report No. | | |

TC 82728

AXIAL LOAD ON 17. IN CYLINDER DUE TO EJECTOR FLOW.

$$P = (33. - 14.7) \frac{\pi}{4} (37.4^2 - 33.46^2) = 4012.7 \text{ LB}$$

AXIAL STRESS

$$\sigma = P/A = 4012.7 / .375 (\cancel{7}) \pi \frac{33.46}{\cancel{7}} = 101.79 \text{ PSI}$$

HYDROSTATIC EQUIVALENT PRESSURE:

$$\sigma = \frac{PD}{4t} = \frac{P \cdot 33.46}{4 (37.5)} \quad P = 32.4 \text{ PSI}$$

HYDROSTATIC TUCKERLING ALLOWABLE (PREVIOUS PAGE) IS
1417. PSI

CONSERVATIVELY ADDING THE TWO PRESSURES

$$P_{\text{TOTAL}} = 32.4 + 14.7 = 47.1 \text{ PSI}$$

$$M.S. = 1417. \text{ PSI} / 4 (47.1) - 1. = \underline{\underline{+7.52}}$$

ORIGINAL PAGE 17
OF POOR QUALITY

| | | | |
|-------------------------|------------------|---|----------------|
| Prepared by: <u>DMT</u> | Date <u>4/24</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page <u>25</u> |
| Checked by: | Date | Title | Model |
| Approved by: | Date | <u>EXTERNAL INJECTOR/DIFFUSER</u> <u>THIRD STAGE INJECTOR TRINOS</u> | Report No. |

R82728

ORIGINAL PART OF POOR QUALITY

204 L S. S.

OUTER CYLINDER, LOAD (3)

$$\sigma = T_D / 2t = 18.3 (49.75) / 2 (.375) = 1213.9 \text{ PSI}$$

$$M.S. = 55. / 4 (1.214) - 1. = \underline{10.32}$$

$$M.S. = 18. / 1.6 (1.214) - 1. = \underline{8.27}$$

OUTER CYLINDER CONJ2 - SEES POSITIVE PRESSURE ONLY
GOOD BY INSPECTION — SEE PAGE 16.

INNER CYLINDER CONJ2 — LOAD (1) REF NASA STRUCT. MANUAL

$$\bar{P} = (28.66 + 33.46) / 4 \cos 8.6^\circ = 15.7$$

$$P_{it} = .92 (23.410^6)^{.75} = 1399.3 \text{ PSI}$$

$$\left(\frac{15.7}{15.7} \right) \left(\frac{15.7}{.375} \right)$$

$$M.S. = 1399 / 4 (14.7) - 1. = \underline{+22.8}$$

HOOP STRESS LOAD CASE (2) → SAME AS INNER CYLINDER

| | | | | | |
|-------------------------|-------------------|---|-----------------|-------|-------|
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| Checked by: | Date: | Title: <u>INTERNAL JETTOR/DIFFUSER</u> | Model: | | |
| Approved by: | Date: | <u>NOZZLE - THIRD STAGE JETTOR</u> | Report No. | | |

TR 82727

ORIGINAL DESIGN
OF POOR QUALITY

JOHL S.S.

CUTTER CYLINDER - LOAD ① HOP STRESS

$$\sigma = PD/2t = 18.3 (51.1) / 2 (.375) = 1247 \text{ PSI}$$

$$M.S. = 55. / 4 (1.247) - 1. =$$

$$+ 10.0 \text{ ULT}$$

$$M.S. = 18. / 1.6 (1.247) - 1. =$$

$$+ 8.02 \text{ YLD}$$

END TRING CUTTER CYLINDER - VERY CONSERVATIVELY IGNORE CORNERS.

LOAD ① - REF. ROKK - 5th ED, PAGE 340. CASE 2F. $r_o = b$



$$M_{123} = q_0^2 L_{14} / C_s = 18.3 (25.5)^2 .0032 / .242$$

$$= 157.57 \text{ IN-LB}$$

$$C_s = .5 [1 - (18.3/25.5)^2] = .242$$

$$L_{14} = \frac{1}{16} \left[1 - \left(\frac{18.3}{25.5} \right)^4 - 4 \left(\frac{18.3}{25.5} \right)^2 \ln \left(\frac{25.5}{18.3} \right) \right] = .0032$$

$$\sigma = 6M / t^2 = 6 (157.57) / .75^2 = 1680.7 \text{ PSI}$$

$$M.S. = 55. / 4 (1.68) - 1. =$$

$$+ 7.18 \text{ ULT}$$

$$M.S. = 18. / 1.6 (1.68) - 1. =$$

$$+ 5.7 \text{ YLD}$$

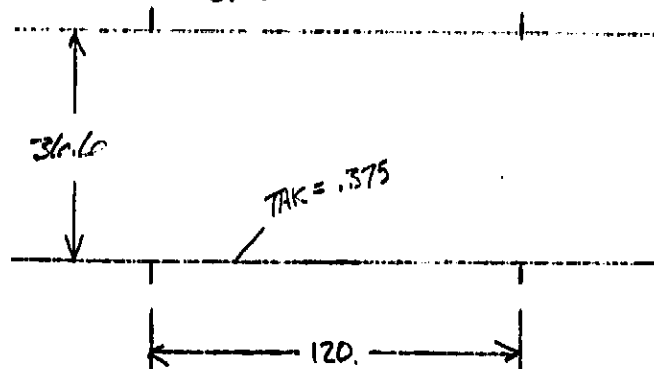
CONSERVATIVE

| | | | |
|------------------|------------|---|-------------|
| Prepared by: TAT | Date: 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 27 |
| Checked by: | Date: | Title: SUBSCALE EJECTOR / DIFFUSER | Model: |
| Approved by: | Date: | STRAIGHT SECTION - THIRD STAGE | Report No.: |

K82731

304 L S.S.

ORIGINAL DESIGN
OF POOR QUALITY



LOAD -

① $-14.7 \text{ PSI} / \text{KT}$

② $139.3 \text{ PSI} / \text{KT}$

BUCKLING - REF NASA STRUCTURES MANUAL, C3.0, P13.

LOAD ①

$D = 133528$. (REF PREVIOUS PAGE)

$Z = 120^2 \sqrt{.9215 / 18.3 (.375)} = 2014$.

$P_c = 35 \pi^2 133528 / 18.3 (120^2) = 175 \text{ PSI}$

$\sqrt{Z} = 1127$.

$K_F = 35$.

$M.S. = 175 / 4 (14.7) - 1. =$

$+ 1.97$ BUCKLING

HOOP STRESS = 717.3 PSI FOR LOAD ① REF PREVIOUS PAGE.
 $M.S. = +23.4$

HOOP STRESS LOAD ②

$T = T_D / ZT = 139.3 \cdot 36.6 / 2 (.375) = 6797 \text{ PSI}$

$M.S. = 25 / 6.797 - 1. =$

$+ 2.67 * YLD$

$M.S. = 70 / 6.797 - 1. =$

$9.3 * ULT$

B-45

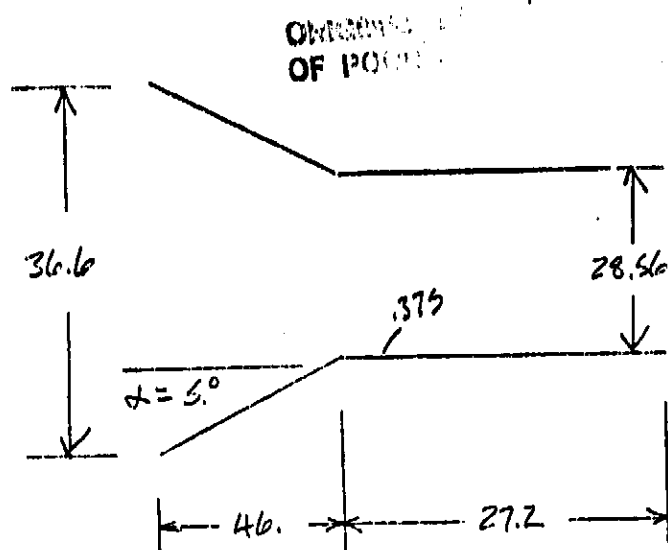
* FACTOR OF SAFETY = 1.0 FOR DETONATIONS PROPOSED.

FORM LMSC 3625-3

| | | | |
|-------------------------|-------------------|---|-----------------|
| Prepared by: <u>WCT</u> | Date: <u>4/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>28</u> |
| Checked by: | Date: | Title: <u>SUBSONIC NOZLE/DIFFUSER</u> | Model: |
| Approved by: | Date: | <u>EXIT TAPER SECTION</u> | Report No.: |

K82730

304 L S.S.



LOAD —

① $-14.7 \text{ PSIG} / \text{ET}$

② $+139.3 \text{ PSIG} / \text{IC}$
DETORTION

③ $+2 \text{ PSIG} / 802^\circ \text{F}$

$\bar{P} = (28.56 + 36.6) / 46.5 = 16.35$

CONC. BUCKLING - REF NASA STRUCTURES MANUAL, C30, P. 67

$$P_{cr} = \frac{.92 E t}{\left(\frac{L}{\bar{r}}\right) \left(\frac{\bar{r}}{t}\right)^{3/2}} = \frac{.92 (28 \times 10^6) .75}{\left(\frac{46}{16.35}\right) \left(\frac{16.35}{.375}\right)^{3/2}} = 547.1 \text{ PSI}$$

M.S. = $547.1 / 4 (14.7) - 1. =$ + 8.3 BUCKLING

CYLINDRICAL BUCKLING - REF AS ABOVE, P. 13

$$D = 28 \times 10^6 (.375^3) / 12 (.9215) = 128746.$$

$$Z = 27.2^2 \sqrt{.9215} / 14.28 (.375) = 132.6$$

$$P_{cr} = 9 \pi^2 128746. / 14.28 (27.2)^2 = 1082. \text{ PSI}$$

$$\tau E = .56 (132.6) = 74.3 \quad K_p = 9$$

M.S. = $1082 / 4 (14.7) - 1. =$ + 17.4

| | | | | | |
|-------------------------|-------------------|---|-----------------|-------|-------|
| Prepared by: <u>TMT</u> | Date: <u>4/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>21</u> | Temp. | Form. |
| Checked by: | Date: | Title: <u>SUBSCALE EXTERIOR/DIFFUSERS</u> | Model: | | |
| Approved by: | Date: | <u>EXIT TAPER SECTION</u> | Report No. | | |

T282730

ORIGINAL PHOTOGRAPH
OF POOR QUALITY

JOHL S.S.

HOOP COMPRESSION - CONE $\sigma = 14.7(36.6)/2(.375) = 717.7 \text{ PSI}$

M.S. = $28/1.6(717) - 1. =$ 23.4 YLD

HOOP COMPRESSION - CYLINDER $\sigma = 14.7(28.56)/2(.375) = 560 \text{ PSI}$

M.S. = $28/1.6(560) - 1. =$ 30.25 YLD

LOAD (2) DETORATION HOOP STRESS

CONE $\sigma = 139.3(36.6)/2(.375) = 6797.7 \text{ PSI}$

M.S. = $70./6.797 - 1. =$ +9.29 ULT *

M.S. = $25./6.797 - 1. =$ +2.67 YLD *

CYLINDER $\sigma = 139.3(28.56)/2(.375) = 5304.7 \text{ PSI}$

M.S. = $70./5.304 - 1. =$ +12.19 ULT *

M.S. = $25./5.304 - 1. =$ +3.71 YLD *

LOAD (3) 2,7516 AT 802°F

CYLINDER $\sigma = 2(36.6)/2(.375) = 97.6 \text{ PSI}$

M.S. = HIGH TSY INSPECTION

* DETORATION FACTOR OF SAFETY = 1.0

| | | | | | |
|-------------------------|--------------------|---|----------------|-------|------|
| Prepared by: <u>WLT</u> | Date: <u>11/44</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page <u>30</u> | Temp. | Rev. |
| Checked by: | Date: | Title: <u>SUBSCALE EXTRACTOR DIFFUSER</u> | Model: | | |
| Approved by: | Date: | <u>PRELIMINARY SUPPORT FINAL CHECK</u> | Report No. | | |

DESIGN LOADS - APPROXIMATE

ORIGINAL DESIGN
OF FOUR QUARTERS

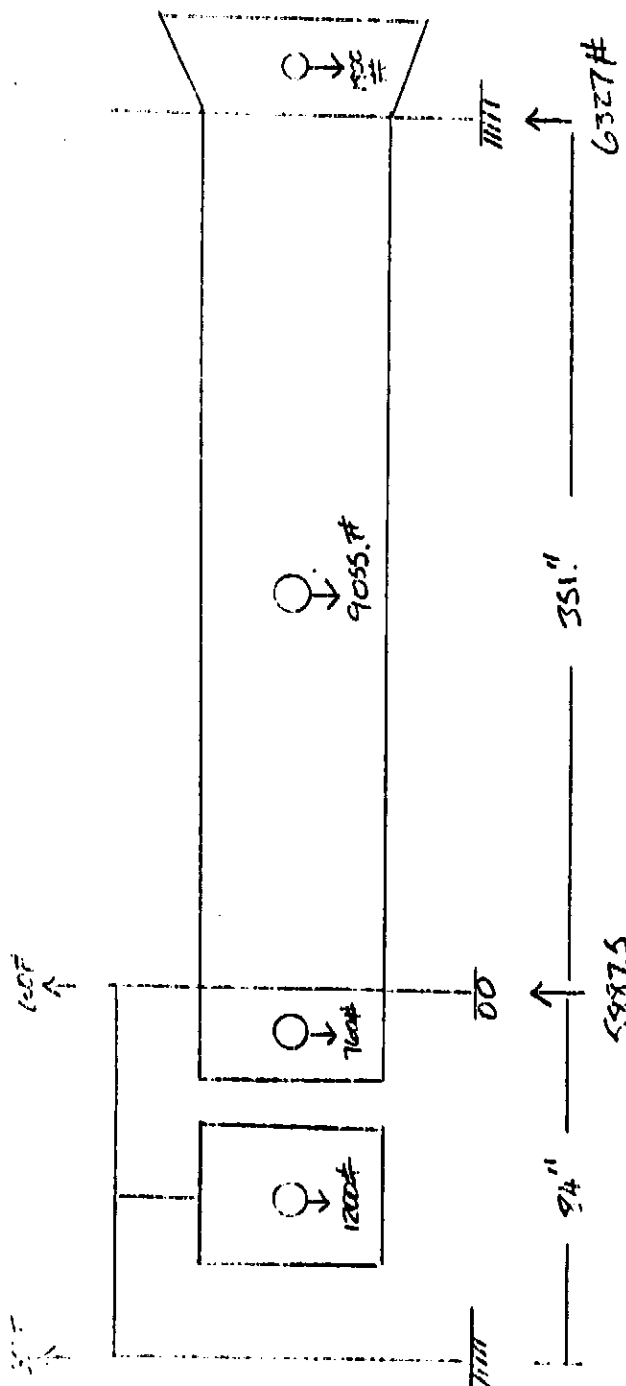
ASSUME MATERIAL IS A-36 STEEL

$F_{TU} = 57 \text{ KSI}$, $F_{TY}/F_{LY} = 36 \text{ KSI}$

A-36 WELD

51 KSI

41 KSI



FACTOR OF SAFETY:

5 ULT

3 YIELD

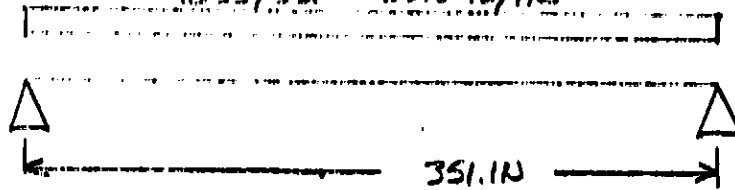
PRELIMINARY ESTIMATE

B-48

| | | | | | |
|------------------|-------------|---|-------------|-------|-------|
| Prepared by: DMT | Date: 11/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 51 | Temp: | Form: |
| Checked by: | Date: | Title: SURTICAL 222222 DIFFUSER | Model: | | |
| Approved by: | Date: | SUPPORT FRAME | Report No.: | | |

DEFLECTION OF 351" SPAN UNDER ITS OWN WEIGHT

$$9055/351 = 25.8 \text{ lb/in}$$



$$\begin{aligned} \text{MAX } \Delta &= 5 w l^4 / 384 EI \\ &= (5) 25.8 (351^4) / 384 (28 \times 10^6) 66164. \\ &= \underline{.0027 \text{ in.}} \end{aligned}$$

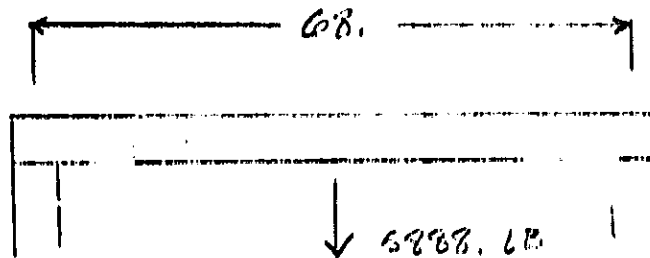
W1222 NOMINAL SECTION $I = \frac{\pi}{64} (36.6^4 - 35.85^4) = 66164.$
AVERAGE

ORIGINAL DESIGN
OF POOR QUALITY

| | | | | | |
|-------------------------|-------------------|---|-----------------|-------|-------|
| Prepared by: DMT | Date: 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 32 | Temp: | Form: |
| Checked by: | Date: | Title: SUBCANS. FACTOR/DIFFUSER | Model: | | |
| Approved by: | Date: | SUPPORT FIGURE | Report No.: | | |

I-BEAM FRAME

ORIGINAL PHOTO
OF POOR QUALITY



ASSUMING- ^{*}ALL FACILITY WEIGHT REACTED HERE - CONSERVATIVE

BEAM IS 6 W15.5 $I = 30.1$ $S = 10.0$

$$M = Wl/4 = 5288(68)/4 = 100096 \text{ IN-LB}$$

$$T = \frac{M}{S} = \frac{100096}{10} = 10009.6 \text{ PSI}$$

$$M.S. = 36K/3 (10.0) - 1. = \quad +.20$$

$$M.S. = 57/5 (10.) - 1. = \quad +.14$$

ULT
CONSERVATIVE

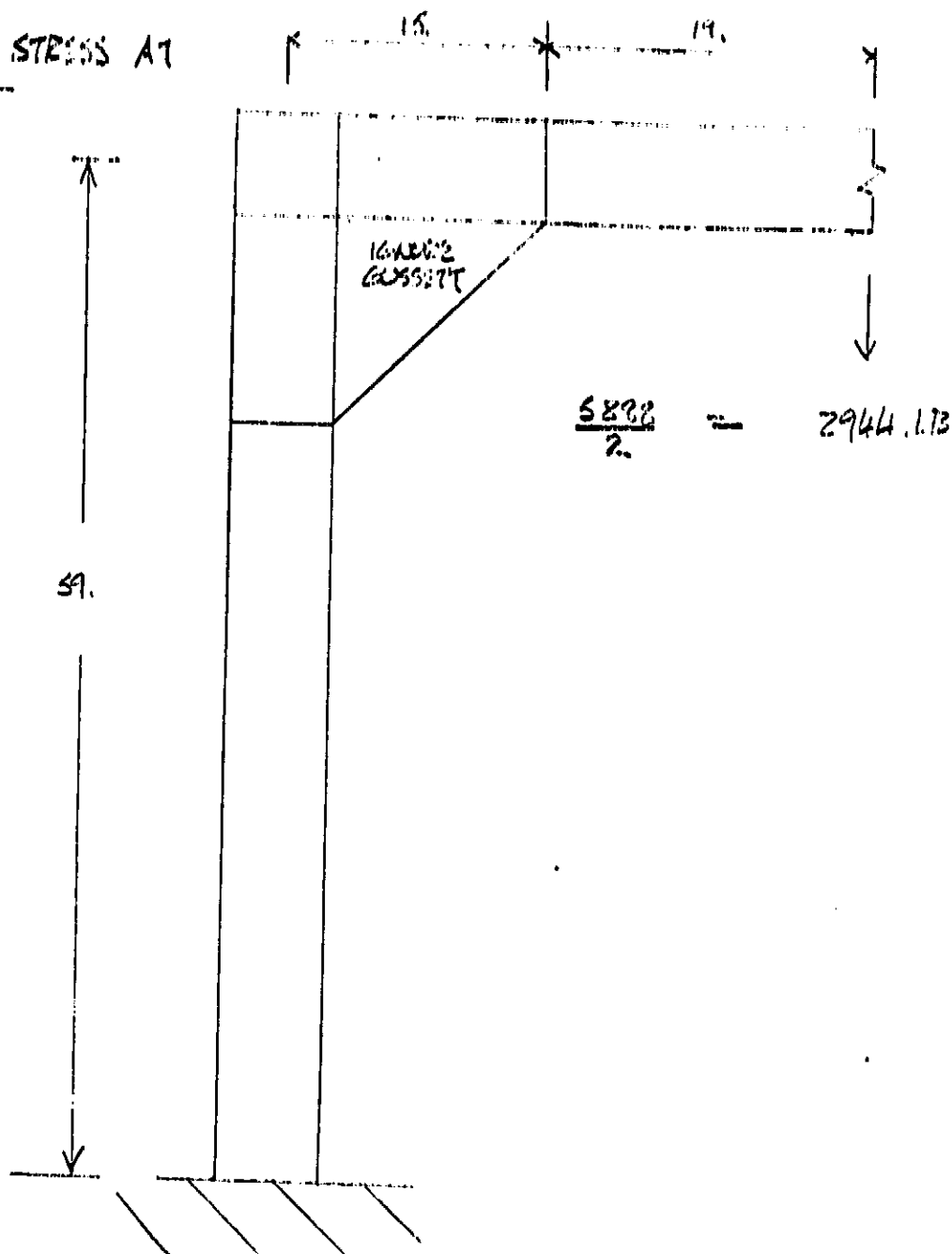
* POSSIBLY DURING CONSTRUCTION.

| | | | |
|------------------|------------|---|-------------|
| Prepared by: DNT | Date: 4/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: 1 |
| Checked by: | Date: | Title: SURCAL? VECTOR/DIFFUSER | Model: |
| Approved by: | Date: | SUSPECT FRAME | Report No.: |

R 82737

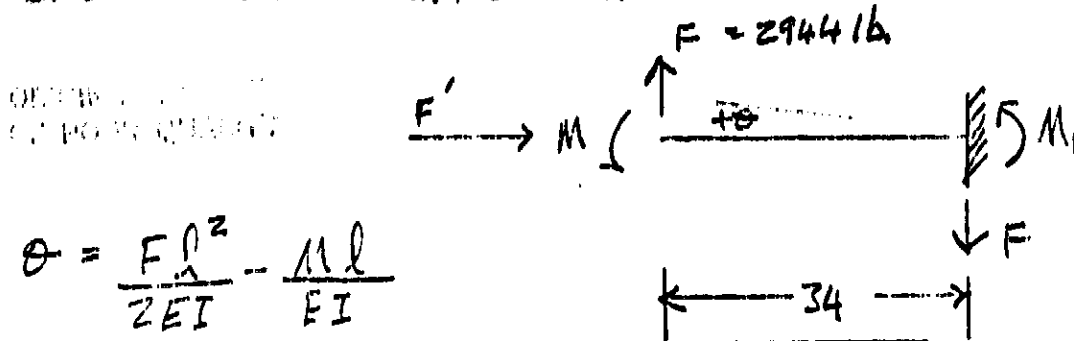
1. FINAL FRAME - CLOSER LOOK

CHARACTER STRESS A1
CONJURE -

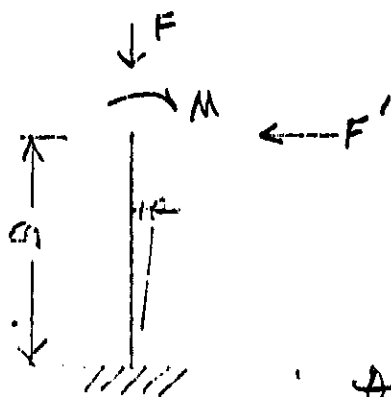


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| Prepared by: <u>TMT</u> | Date: <u>4/64</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page <u>1</u> temp. <u>1</u> perm. <u>1</u> |
| Checked by: | Date: | Title: <u>SUBSONIC INLET/DIFFUSER</u> | Model: |
| Approved by: | Date: | <u>SUPPORT FRAME</u> | Report No.: |

IGNORE GUSSET — CONSERVATIVE



$$\theta = \frac{F l^2}{2EI} - \frac{M l}{EI}$$



$$\theta = \frac{M l'}{EI} - \frac{F' l'^2}{2EI}$$

$$\Delta = \frac{F' l'^3}{3EI} = \frac{M l'^2}{2EI} \quad F' = \frac{3M}{2l'}$$

$$\therefore \theta = \frac{M l'}{EI} - \frac{3}{4} \frac{M l'}{EI} = \frac{M l'}{4EI}$$

$$\frac{M l'}{4EI} = \frac{F l^2}{2EI} - \frac{M l}{EI} \quad l' = 59 \quad l = 34$$

$$14.75 M = 2944 \frac{(34)^2}{2} - 34 M \quad M = 34905 \text{ IN-LB}$$

$$M_1 = 2944 (34) - 34905 = 65191 \text{ IN-LB}$$

$$\tau = M/s = 65191 / 10 = 6519.7 \text{ PSI}$$

$$M.S. = 36 / 3 (6.52) - 1. = +.84 \text{ YLD}$$

$$M.S. = 57 / 5 (6.52) - 1. = +.74 \text{ YLD}$$

B-52

CONSERVATIVE

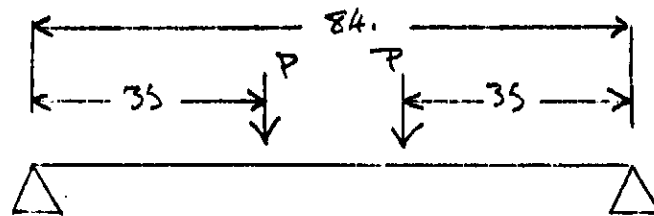
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|--------------------------|-------------------|---|-----------------|--------|--------|
| Prepared by: <u>DALT</u> | Date: <u>4/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page: <u>33</u> | Temp.: | Perf.: |
| Checked by: | Date: | Title: <u>SUBSCALE EJECTOR/DIFFUSER</u> | Model: | | |
| Approved by: | Date: | <u>SUPPORT FRAME</u> | Report No.: | | |

TECHNICAL R 82737

SLIDING BEARING PIPE → OD = 4.25 IN / ID = 3.15 IN

CASE 1 — PLUG WEIGHT IS SUPPORTED BY 2 SLIDING PIPES
WHAT IS THE DEFLECTION? —

$$I = \pi (4.25^4 - 3.15^4) / 64 = 11.18 \text{ IN}^4$$



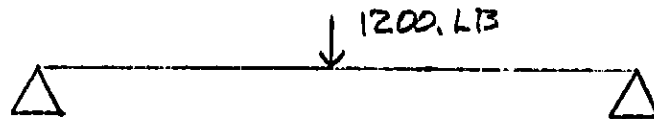
ORIGINAL PAGE IS
OF POOR QUALITY

$$2P = \frac{1200 \text{ LB}}{2} \quad P = 300 \text{ LB}$$

$$\Delta_{\text{MAX}} = \frac{P a}{24 EI} (3l^2 - 4a^2) = \frac{300(35)(21168 - 4900)}{24(28)(10^6)(11.18)}$$

$$= .0215 \text{ IN.}$$

CASE 2 — PLUG WEIGHT IS SUPPORTED BY ONE PIPE —



$$M = w l / 4 = 1200 (84) / 4 = 25200 \text{ IN}^4$$

$$\sigma = M c / I = 25200 (4.25) / 2 (11.18) = 4789 \text{ PSI}$$

$$\text{M.S.} = 57 / 5 (4.79) - 1, \quad \underline{\underline{+1.37}}$$

$$\text{M.S.} = 36 / 3 (4.79) - 1, \quad \underline{\underline{+1.50}}$$

| | | | | | |
|-------------------------|-------------------|---|------------|-------|-------|
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| Approved by: | Date: | METAL STANDARD | Report No. | | |

SECTION DEALER
OF POOR QUALITY

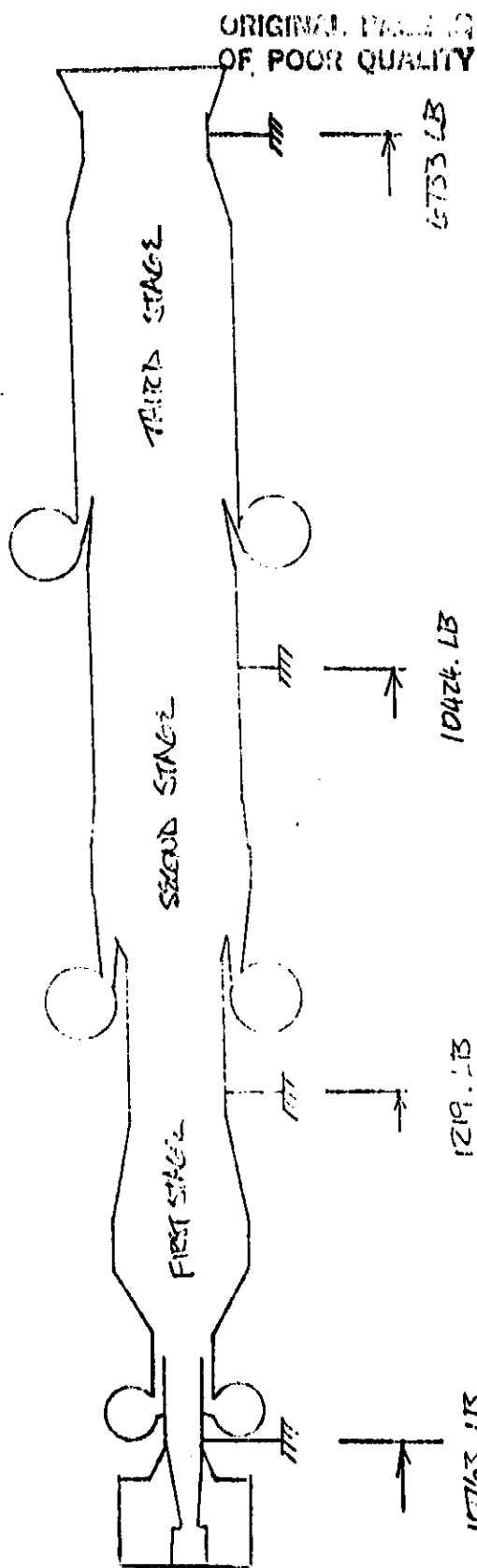
DIMENSIONS of Seamless and Welded STEEL PIPE

ASA-836.10 and 836.19

| NOMINALS PIPE SIZE | OUT- SIDE DIAM. | NOMINAL WALL THICKNESS FOR | | | | | | | | | | | | | | | |
|--------------------------|-----------------------|----------------------------|---------------|--------------|--------------|--------------|---------------|--------------|---------------|-----------------|--------------|---------------|---------------|---------------|---------------|-----------------|--|
| | | SCHED. 5S | SCHED. 10S | SCHED. 10 | SCHED. 20 | SCHED. 30 | STAND- ARD | SCHED. 40 | SCHED. 40S | EXTRA STRONG | SCHED. 60 | SCHED. 100 | SCHED. 120 | SCHED. 140 | SCHED. 160 | EXTRA STRONG | |
| 1/8 | 0.405 | ..... | 0.049 | ..... | ..... | ..... | 0.068 | 0.068 | ..... | 0.095 | 0.095 | ..... | ..... | ..... | ..... | ..... |  |
| 1/4 | 0.540 | ..... | 0.065 | ..... | ..... | ..... | 0.088 | 0.088 | ..... | 0.119 | 0.119 | ..... | ..... | ..... | ..... | ..... |  |
| 3/8 | 0.675 | ..... | 0.088 | ..... | ..... | ..... | 0.091 | 0.091 | ..... | 0.126 | 0.126 | ..... | ..... | ..... | ..... | ..... |  |
| 1/2 | 0.840 | 0.065 | 0.083 | ..... | ..... | ..... | 0.109 | 0.109 | ..... | 0.147 | 0.147 | ..... | ..... | ..... | 0.188 | 0.294 | |
| 3/4 | 1.050 | 0.065 | 0.083 | ..... | ..... | ..... | 0.113 | 0.113 | ..... | 0.154 | 0.154 | ..... | ..... | ..... | 0.219 | 0.308 | |
| 1 | 1.315 | 0.085 | 0.109 | ..... | ..... | ..... | 0.133 | 0.133 | ..... | 0.179 | 0.179 | ..... | ..... | ..... | 0.250 | 0.350 | |
| 1 1/4 | 1.660 | 0.085 | 0.109 | ..... | ..... | ..... | 0.140 | 0.140 | ..... | 0.191 | 0.191 | ..... | ..... | ..... | 0.250 | 0.382 | |
| 1 1/2 | 1.900 | 0.065 | 0.109 | ..... | ..... | ..... | 0.145 | 0.145 | ..... | 0.200 | 0.200 | ..... | ..... | ..... | 0.281 | 0.400 | |
| 2 | 2.375 | 0.065 | 0.109 | ..... | ..... | ..... | 0.154 | 0.154 | ..... | 0.218 | 0.218 | ..... | ..... | ..... | 0.344 | 0.436 | |
| 2 1/2 | 2.875 | 0.083 | 0.120 | ..... | ..... | ..... | 0.203 | 0.203 | ..... | 0.276 | 0.276 | ..... | ..... | ..... | 0.375 | 0.552 | |
| 3 | 3.5 | 0.083 | 0.120 | ..... | ..... | ..... | 0.216 | 0.216 | ..... | 0.300 | 0.300 | ..... | ..... | ..... | 0.438 | 0.600 | |
| 3 1/2 | 4.0 | 0.083 | 0.120 | ..... | ..... | ..... | 0.226 | 0.225 | ..... | 0.318 | 0.318 | ..... | ..... | ..... | ..... | ..... |  |
| 4 | 4.5 | 0.083 | 0.120 | ..... | ..... | ..... | 0.237 | 0.237 | ..... | 0.337 | 0.337 | ..... | 0.438 | ..... | 0.531 | 0.674 | |
| 5 | 5.563 | 0.109 | 0.134 | ..... | ..... | ..... | 0.258 | 0.258 | ..... | 0.375 | 0.375 | ..... | 0.500 | ..... | 0.625 | 0.750 | |
| 6 | 6.625 | 0.109 | 0.134 | ..... | ..... | ..... | 0.280 | 0.280 | ..... | 0.432 | 0.432 | ..... | 0.562 | ..... | 0.719 | 0.864 | |
| 8 | 8.625 | 0.109 | 0.148 | ..... | 0.250 | 0.277 | 0.322 | 0.322 | 0.406 | 0.500 | 0.500 | 0.594 | 0.719 | 0.812 | 0.906 | 0.875 | |
| 10 | 10.75 | 0.134 | 0.165 | ..... | 0.250 | 0.307 | 0.365 | 0.365 | 0.500 | 0.500 | 0.594 | 0.719 | 0.844 | 1.000 | 1.125 | 1.000 | |
| 12 | 12.75 | 0.156 | 0.180 | ..... | 0.250 | 0.330 | 0.375 | 0.406 | 0.562 | 0.500 | 0.688 | 0.844 | 1.000 | 1.125 | 1.312 | 1.000 | |

FORM LMSC 3528-3

| | | | | | |
|-------------------------|-------------------|---|------------|-------|------|
| Prepared by: <u>MIT</u> | Date: <u>6/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page | Temp. | Pin. |
| Checked by: | Date: | Title: <u>SUTSKAL EXHAUST/DIFFUSER</u> | Model: | | |
| Approved by: | Date: | <u>SUPPORT FRAME</u> | Report No. | | |



AXIAL REACTIONS
 EXERCISED ON THE PIPINGS BY THE SUPPORT STRUCTURE

$$\frac{10424}{(4) \cos 45} = 7485 \text{ LB}$$

DWG. TUBE JOINT LOAD

$$\frac{10763}{(3) \cos 45} = 5073 \text{ LB}$$

DWG. TURBOCHARGER LOAD

| | | | | | |
|---------------------|------------|---|------------|-------|--------|
| Prepared by: T.M.T. | Date: 6/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page | Temp. | Perin. |
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| Approved by: | Date: | SUPPORT FRAME | Report No. | | |

DIAGONAL TURNBUCKLES REACTING AXIAL THRUST LOADS -

$$\text{MAX MAGNITUDE} = \frac{10763}{(3) \cos 45^\circ} = 5073 \text{ LB.}$$

CLEVIS MS27120 1.0 IN. DIA

ULT ALLOWABLE = 33100 LB

TURNBUCKLE MS27954 1.0 IN. DIA

ULT ALLOWABLE = 38000 LB.

$$M.S. = 33.1 / 5(5.073) - 1. = \underline{\underline{+ .31}}$$

APPROVED BY
OF FOUR EJECTOR

| | | | | | |
|-------------------|------------|---|------------|-------|--------|
| Prepared by: TALT | Date: 6/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page | Temp. | Print. |
| Checked by: | Date: | Title: SUBSALL STRUCTURE/DIFFUSION | Model | | |
| Approved by: | Date: | SUPPORT FRAME | Report No. | | |

MY AXIAL TENSION IS 10424 LB BEFORE THIRD STAGE SECTOR.

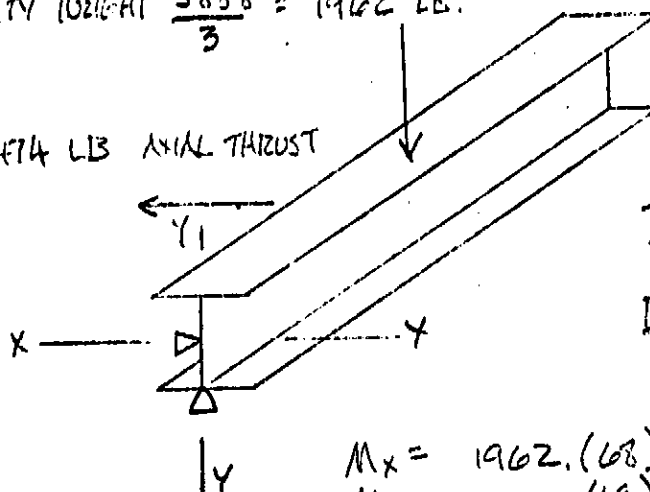
ACTING ON TOP OF FRAME:

TOTAL L = 68.1N.

FRAGILITY WEIGHT $\frac{5888}{3} = 1962$ LB.

$\frac{10424}{3} = 3474$ LB AXIAL THRUST

TENNIS 6015.5



$I_x = 30.1$ $S_x = 10.0$

$I_y = 9.67$ $S_y = 3.23$

$M_x = 1962 \cdot (68) / 4 = 33354$ IN-LB

$M_y = 3474 \cdot (68) / 4 = 59058$ IN-LB

$$\sigma = \frac{M_x}{I_x} = \frac{M_y}{I_y} = \frac{33354}{10} + \frac{59058}{3.23} = 21619.6 \text{ PSI}$$

$$MS = 57/5 (21.62) - 1. = -47$$

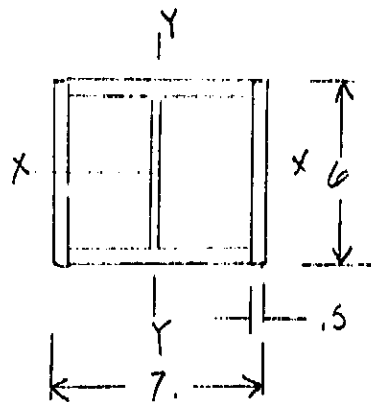
$$MS = 36/3 (21.62) - 1. = -44$$

WILL BE REDESIGNED — SEE NEXT PAGE

| | | | | | |
|------------------|------------|---|------------|-------|------|
| Prepared by: LMT | Date: 2/54 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page | Temp. | Hum. |
| Checked by: | Date: | Title: NOSE: INLET/DIFFUSER | Model | | |
| Approved by: | Date: | CONCRETE FRAME | Report No. | | |

ALL AXIAL REACTIONS & MAX FACILITY WEIGHT
ACTING ON TOP OF FRAME

ORIGINAL PAGE IS
OF POOR QUALITY



6 @ 15.5 PLUS 1/2 IN. PLATE BOTH SIDES

$$I_x = 30.1 + \frac{1 \cdot (6)^3}{12} = 48.1 \text{ IN}^4$$

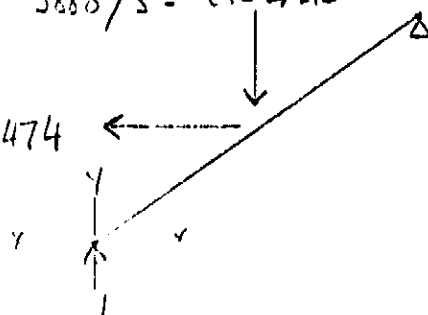
$$I_y = 9.67 + \frac{6 \cdot (7^3 - 5.99^3)}{12} = 73.17 \text{ IN}^4$$

$$AREA = 4.56 + 6 = 10.56$$

$$FACILITY WEIGHT \frac{5888}{3} = 1962 \text{ LBS}$$

$$\text{AXIAL THRUST} \frac{10424}{3} = 3474$$

$$L = 68 \text{ IN.}$$



$$M_x = 1962 \cdot (68) / 4 = 33354$$

$$M_y = 3474 \cdot (68) / 4 = 59058$$

$$T = \sum \frac{M C}{I} = \frac{33354(3)}{48.1} + \frac{59058(3.5)}{73.17} = 4905 \text{ PSI}$$

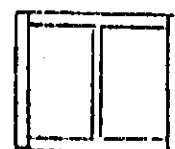
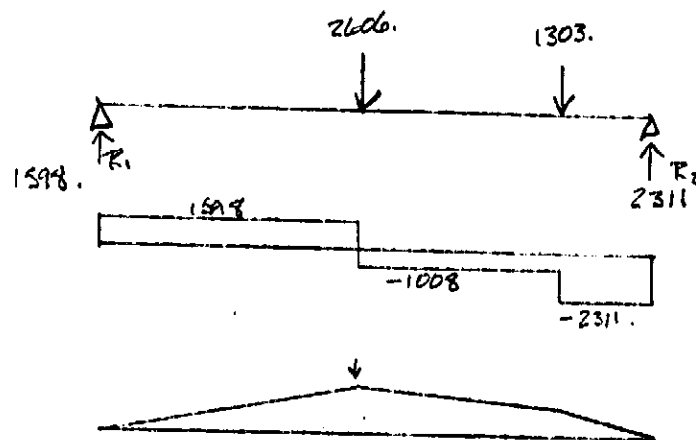
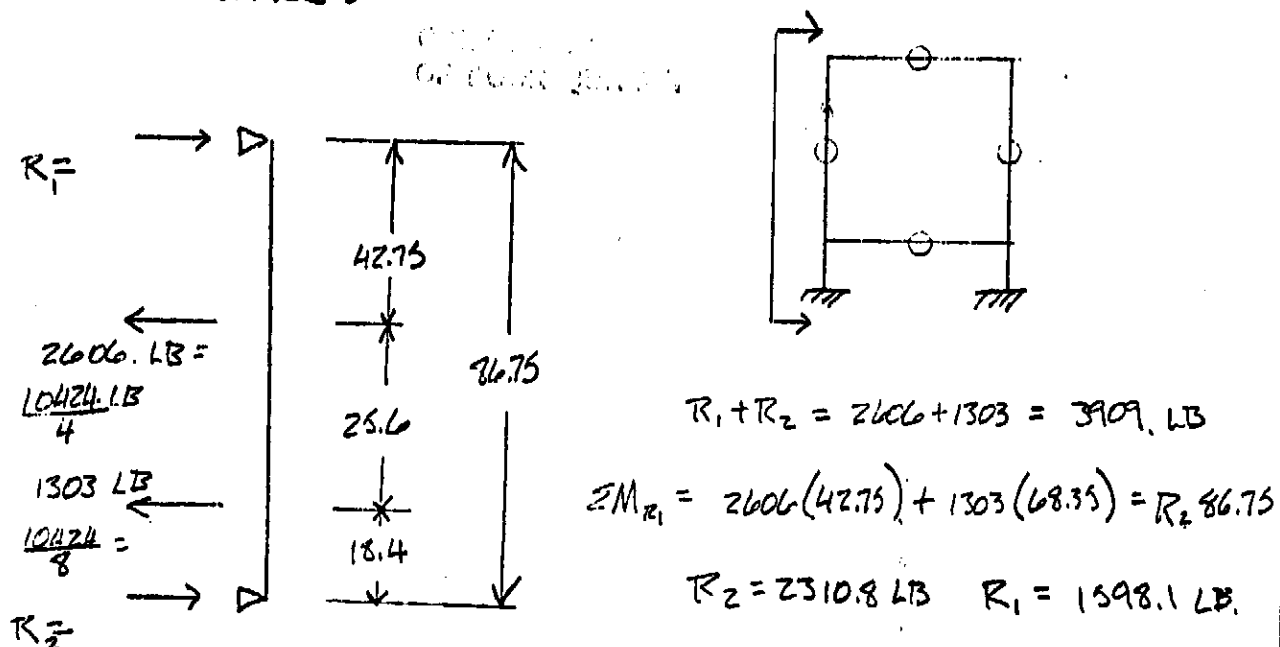
AGAINST FIELD ALLOWABLES:

$$M.S. = 51. / 5(4.9) - 1. = +1.08$$

$$M.S. = 41. / 3(4.9) - 1. = +1.78$$

| | | | | | |
|------------------|------------|---|------------|-------|-------|
| Prepared by: DMT | Date: 6/64 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page | Temp. | Perm. |
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| Approved by: | Date: | | Report No. | | |

- THIRD STAGE FRAME WHERE AXIAL REACTION IS TAKEN AT FOUR PLACES
- TOP OF FRAME IS GOOD PER PREVIOUS CALCULATIONS.
- SIDE STAYS:



PROPERTIES
PREVIOUS PAGE

$$\text{MAX MOMENT} = 1598(42.75) = 68314 \text{ LB}$$

$$\sigma = 68314(3.5) / 73.17 = 3267 \text{ PSI}$$

$$\text{ON WELD } MS = 51 / 5(3.27) - 1. =$$

$$MS = 41 / 3(3.27) - 1. =$$

TESTED SECTION

$+2.11$
 $+3.17$

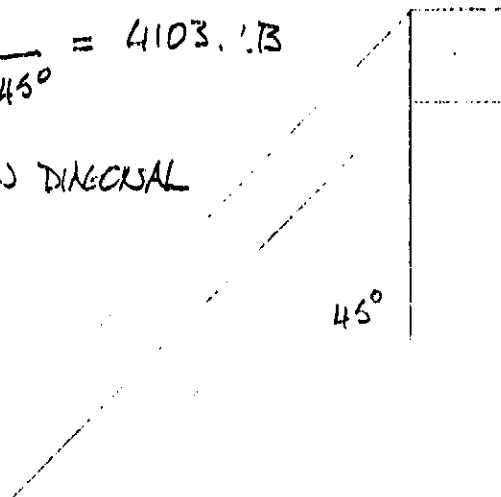
| | | | | | |
|-------------------------|-------------------|---|------------|-------|-------|
| Prepared by: <u>ENT</u> | Date: <u>6/84</u> | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page | Temp. | Perm. |
| Checked by: | Date: | Title: <u>DIAGONAL BRACE/DIFFUSER</u> | Model: | | |
| Approved by: | Date: | <u>SUPPORT STRUCTURE</u> | Report No. | | |

DIAGONAL BRACE AT FEMUR

$$\text{TOTAL AXIAL LOAD} = 1518 \text{ (PREVIOUS PAGE)} + 1303 \text{ (TOP REACTION)} \\ = 2901 \text{ LBS}$$

$$\frac{2901}{\sin 45^\circ} = 4103 \text{ LBS}$$

IN DIAGONAL

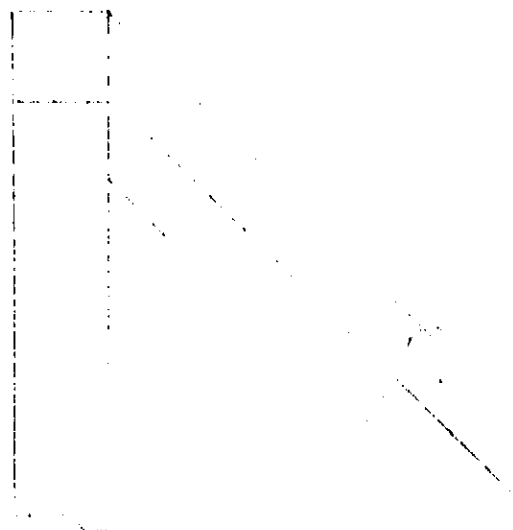


ORIGINAL DESIGN
OF POOR QUALITY

COMPRESSIVE STRESS:

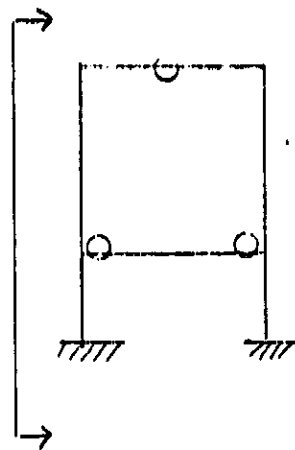
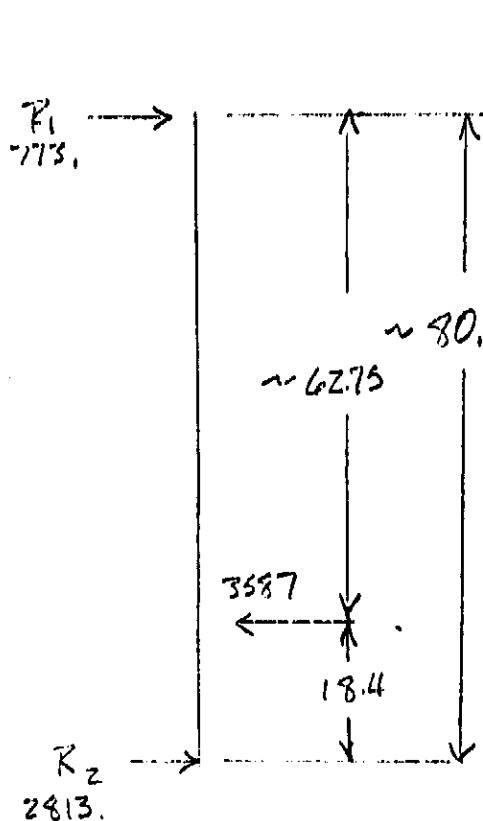
$$\sigma = \frac{P}{A} = \frac{4103}{4.56} = 899 \text{ PSI}$$

BRACE SHOULD BE IN TENSION
BY INCREASING SLOPE



| | | | | | |
|------------------|------------|---|-------|-------|------------|
| Prepared by: TMT | Date: 6/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page | Temp. | Perm. |
| Checked by: | Date: | Title | Model | | |
| Approved by: | Date: | TUSCALA ESTABL/DIFFUSER SUPPORT STRUCTURES | | | Report No. |

— FIRST STAGE EJECTOR WHERE REACTION LOADS ARE TAKEN TO FRAME AT 3 PLACES.



$$\text{LOAD} = 10763 / 3 = 3587 \text{ LB}$$

$$R_1 + R_2 = 3587$$

$$2/11 = 62.75 (3587) = 80 R_2$$

$$R_2 = 2813 \text{ LB} \quad R_1 = 773 \text{ LB}$$

$$\begin{aligned} \text{Moment} &= 2813 (18.4) \\ &= 51759 \text{ IN-LB} \end{aligned}$$

$$\text{AT WELD} \quad \sigma = \frac{M}{I} = 51759 (3.5) / 73.17 = 2475$$

$$M.S. = 51 / 5 (2.48) - 1 = +3.11$$

$$M.S. = 41 / 3 (2.48) - 1 = +14.51$$

* CHECKED BY 11326 6/15/84

| | | | | | |
|------------------|------------|---|------------|-------|-------|
| Prepared by: DNT | Date: 6/84 | LOCKHEED MISSILES & SPACE COMPANY, INC. | Page | Temp. | Perm. |
| Checked by: | Date: | Title: SUBSCALE INJECTOR/DIFFUSER | Model: | | |
| Approved by: | Date: | SUPPORT SECTION | Report No. | | |

FASTENERS TO RAIL

ORIGINAL FASTENERS
OF POOR QUALITY

PATTERN OF 8 $\frac{1}{2}$ " 301 ST ST $F_{SU} = 50$ KSI

$$P_{ALL\ SU} = 50 \text{ KSI} \pi .5^2 / 4 = 9.817 \text{ KSI}$$

MAX FASTENER PATTERN'S SHEAR LOAD IS 2901. LB
FROM DIAGONAL BRACE TO FRAME WITH FOUR AXIAL
THRUST LOAD PICKUPS -

$$2901 / 8 = 362. \text{ LB / FAS SHEAR}$$

$$MS = 9.8 / 5 (.36) - 1. = \underline{\underline{+ 4.44}}$$

Appendix C
LIST OF DRAWINGS AND BILL OF MATERIALS

SUBSCALE EJECTOR/DIFFUSER DRAWING LIST

| Drawing | Number |
|---|---------|
| Site Plan | R82733 |
| Plan & Evaluation | R82732 |
| Subscale Ejector/Diffuser Assembly | R82734 |
| Ejector Inlet Piping Planform | R82736 |
| Inlet Plate - Nozzle Simulator | R82701 |
| H ₂ Diffuser - Nozzle Simulator | R82700 |
| H ₂ Cylinder - Nozzle Simulator | R82702 |
| Nozzle Body- Detail | R82706 |
| Altitude Simulation Cell - Nozzle Simulator | R82704 |
| Altitude Cell End Plate - Nozzle Simulator | R82708 |
| Nozzle Discharge Tube - Nozzle Simulator | R82709 |
| Expansion Section - Nozzle Simulator | R82710 |
| Ejector Ring 1st Stage | R82714 |
| Nozzle Piece 1st Stage Ejector | R82716 |
| Adjustable Plug Assy 1st Stage | R82715 |
| Compression Section 1st Stage | R82717 |
| 1st Stage to 2nd Stage Mixing Tube | R82718 |
| Ejector Ring 2nd Stage Ejector | R82723A |
| Nozzle Piece 2nd Stage Ejector | R82723B |
| Adjustable Plug Assy 2nd Stage | R82724 |
| 2nd Stage Mixing Tube | R82726 |
| Ejector Ring 3rd Stage Ejector | R82728 |
| Nozzle Piece 3rd Stage Ejector | R82727 |
| Adjustable Plug Assy 3rd Stage Ejector | R82729 |
| Mixing Section 3rd Stage Ejector | R82731 |
| Exit Taper Section 3rd Stage Ejector | R82730 |
| Support Carriage | R82735 |
| Typical Support Buckle | R82738 |
| Structural Support 2nd Stage | R82737 |

BILL OF MATERIALS
(See Assembly R82734)

| Qty Rqd. | Part or Identifying No. | Nomenclature or Description | Material Specification | Zone | Item No. |
|-------------|----------------------------|--|---------------------------|-------|-------------|
| 1 | R82701-1 | Inlet Plate | 304L | 4 | 1 |
| 1 | R82700-1 | H ₂ Diffuser | 304L | 4 | 2 |
| 1 | R82702-1 | H ₂ Cylinder | 304L | 4 | 3 |
| 1 | R82706-1 | Nozzle Body | 304L | 4 | 4 |
| 1 | R82704-1 | Alt Simulator Cell | 304L | 4 | 5 |
| 1 | R82708-1 | Alt Cell End Plate | 304L | 4 | 6 |
| 1 | R82709-1 | Nozzle Discharge Tube | 304L | 4 | 7 |
| 1 | R82710-1 | Expansion Section | 304L | 4 | 8 |
| 1 | R82714-1 | Ejector Ring 1st St. | 304L | 3 | 9 |
| 1 | R82716-1 | Nozzle Piece 1st St. | 304L | 3 | 10 |
| 1 | R82715-1 | Adj. Plug 1st St. | 304L | 3 | 11 |
| 1 | R82717-1 | Compression Sec. 1st St. | 304L | 3 | 12 |
| 1 | R82718-1 | 1st to 2nd St. Mixing Tube | 304L | 3 | 13 |
| 1 | R82723A-1 | Ejector Ring 2nd St. | 304L | 2 | 14 |
| 1 | R82723B-1 | Nozzle Piece 2nd St. | 304L | 2 | 15 |
| 1 | R82724-1 | Adj. Plug 2nd St. | 304L | 2 | 16 |
| 1 | R82726-1 | 2nd St. Mixing Tube | 304L | 2 | 17 |
| 1 | R82728-1 | Ejector Ring 3rd St. | 304L | 1 | 18 |
| 1 | R82727-1 | Nozzle Piece 3rd St. | 304L | 1 | 19 |
| 1 | R82729-1 | Adj. Plug 3rd St. | 304L | 1 | 20 |
| 1 | R82731-1 | 3rd St. Mixing Sec. | 304L | 1 | 21 |
| 1 | R82730-1 | Exit Taper Section | 304L | 1 | 22 |
| 8 | | Parkertron LDT 2" Bore 3" Stroke | | 2 + 3 | 23 |
| 4 | | Parker Fluid Power Atlanta, Ga. Parkertron LDT 2" Bore 6" Stroke | | 1 | 24 |
| 40 | | Parker Fluid Power Atlanta, Ga. SWRM-14 Rod End | Super St. Alloy | 1,2,3 | 25 |
| | | Southwest Products Co. Monrovia, Calif. | Chrome Plate | | |
| 69 | MS27120-11 | Clevis, Rod End | St. Type (Forged) | 1,2,3 | 26 |
| 69 | MS27954-6 | Turnbuckle | St. Type (Forged) | 1,2,3 | 27 |
| 10 | MS27120-39 | Clevis, Rod End | St. Type (Forged) | 1,2,3 | 28 |
| 10 | MS27954-21 | Turnbuckle | St. Type (Forged) | 1,2,3 | 29 |

NOTE: Pertaining to fasteners:

Bolts will be MS16208; washers will be MS15795; nuts will be MS16203;
screw, cap, socket head - hexagon MS16996.